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THE BROWN ROT OF THE LEMON.

By RALPH E. SMITH.

Assisted by H. J. Ramsey, E. H. Smith, E. B. Babcock and C. O. Smith.

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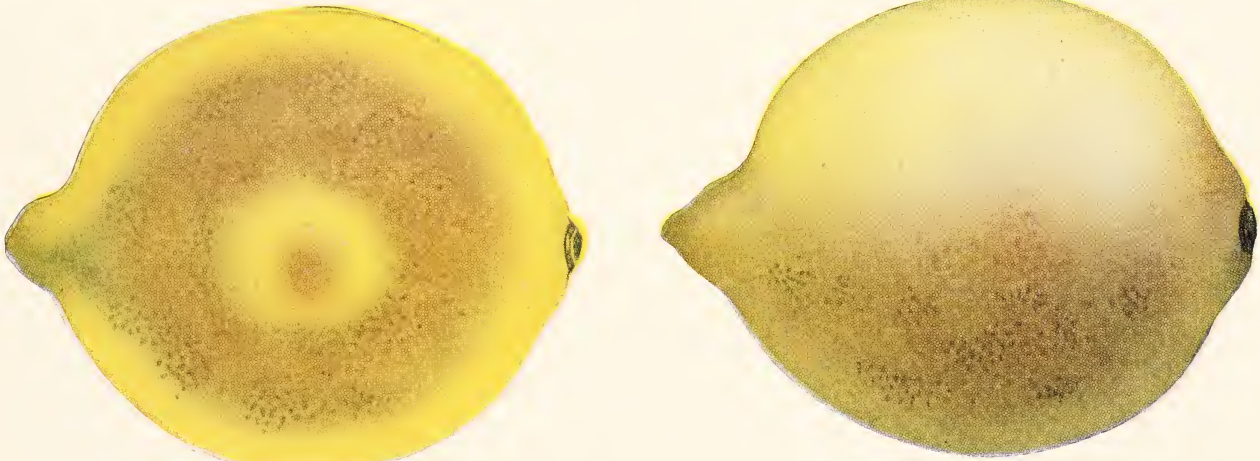

THE BROWN ROT OF THE LEMON.

By RALPH E. SMITH.

Assisted by H. J. Ramsey, E. H. Smith, E. B. Babcock, and C. O. Smith.

The subject of this bulletin is a peculiarly virulent, rapid-spreading form of decay of lemons occurring in southern California. It has been named "Brown Rot" by the growers in distinction from the ordinary "Blue Mould" rot caused by the *Penicillium* fungus, the usual form of decay in citrus fruit. Great losses have been experienced from this source during the past few years, and it has remained for this investigation to determine the cause and means of control of the trouble.

The history of the lemon industry in California has been one of much vicissitude and uncertainty, and has been marked particularly by a decidedly sudden and apparently permanent change from a condition of deep depression and discouragement to one of unusual profit and prosperity. This change came about most largely during the season of 1904-05, and was so complete as to transform the whole aspect of the business.

The California lemon as a commercial product has had a poor reputation in the markets of the country, which it has only recently begun to live down. The defect has been in keeping quality, in which respect the native product, as compared with imported fruit, has been notably deficient. The reasons for this may have been several, but for present purposes it need simply be said that by improvements in their methods of handling the fruit the lemon growers and shippers of the State, taking advantage of the improved market conditions brought about by the short foreign crop of 1904-05, have largely overcome the prejudice against the keeping quality of the California lemon, and are doing so more and more with every car that leaves the State. Supported by the abnormally high prices of the last three seasons, our lemon industry has improved and strengthened itself all along the line to a really remarkable extent. Under the influence of the leaders of the industry methods of both production and handling have been improved, the coöperative selling associations have strengthened and improved their condition and enlarged the scope of their influence, and the whole lemon industry has entered upon a period in which there is nothing but encouragement for the future.

Excessive decay, in curing, transit, and on the market has been the great trouble with the California lemon which has kept it from enjoying the appreciation of its otherwise excellent qualities to which it is properly entitled. The tree is peculiar in that it produces fruit at all seasons of the year, which fruit is not allowed to mature naturally on the tree to normal ripeness and size, but is picked in a green condition on reaching a certain size and then stored for some time (several weeks or months) to cure or ripen. A well-cured lemon does not rot. It can scarcely be made to decay. When the skin has been dried out to the ideal firm texture, thinness and yellow color, under the proper conditions of atmospheric moisture for good curing, the lemon can be kept for months without decaying, until it has completely dried up and mummified.

It has been demonstrated that most of the decay which often occurs so extensively during the period from the tree to the consumer, and which formerly was nearer the rule than the exception in many houses, is directly traceable to bruising of the fruit caused by rough handling in the field and packing house; likewise that by careful handling this rot can be almost entirely eliminated. One of the greatest advances of the California lemon industry has come about through the recognition of this simple fact. Decay of this sort is commonly caused by the so-called "Blue Mould" fungus, species of *Penicillium,* a fungus which is not particularly active as a parasite, but which is ever ready to attack and quickly causes the decay of citrus fruit which has been bruised or weakened in any way. *Penicillium* is the ever present, and, until recently, the only recognized cause of citrus decay in this State.* The recent improvement in the lemon industry just referred to has come about largely by the simple exercise of more care in handling the fruit to prevent bruising, and by improved methods of curing.

Going back for a period of five or six years it has gradually come about that the lemon people have begun to recognize that some further factor than the ordinary blue mould which they knew how to handle was causing decay of their fruit. As early as the season of 1901 the more observant of them had come to the conclusion that something entirely distinct from the ordinary *Penicillium* rot, or at any rate, from their standpoint, a different proposition for handling, was confronting them. This fact was recognized earliest by the leaders in the business, since they were handling ordinary decay successfully and could quickly recognize a new condition, while in the less carefully conducted houses the usual amount of decay up to a very recent period was so great that a new cause coming in had little effect upon the general average

*See Woodworth, Orange and Lemon Rot. Bull. 139, Cal. Agr'l Expt. Sta.
Powell, The Handling of Fruit for Transportation. Year Book U. S. Dept. of Agr., 1905.

or upon the minds of those in charge. When, however, in the best houses, the shrinkage between picking and packing rose from 10 to 20 or 30 per cent, when an amount of fruit equal to 10 per cent of the entire output rotted in the house and was thrown away from a cause different from anything encountered in previous experience, when a large amount of extra help was constantly required in handling the fruit in order to keep down losses to even these abnormally high amounts, when fruit in transit decayed in an inexplicable manner and to an unheard of extent, and when the losses by decay in single houses rose to from ten to thirty thousand dollars per year above that which could be accounted for by any known cause, then it became evident that something of an unusual nature was going on, and that something must be done to meet this situation or the lemon business would again go back into a condition of depression and uncertainty.

This was what actually occurred in many houses in southern California during the period from 1901 to 1905. Excessive decay occurred, whole pickings or entire lots of fruit were lost in some cases, and, except that something new and peculiar was at work, practically nothing was known as to the cause or remedy of the trouble. Some maintained that the decay was nothing more than a severe attack of the ordinary blue-mould fungus, but the most observant of those who handled the fruit soon became convinced that this was not the case.

In the spring of 1905 the "Lemon Men's Club," an organization of the leaders in the California lemon business, brought this matter to the attention of the State Experiment Station. Arrangements were made between Mr. C. C. Teague of the Limoneira Lemon Company and the writer for commencing an investigation of the trouble, and a financial contribution was made by the members of the club to assist in the work. The investigation was inaugurated by placing two assistants in the field, one at the Limoneira Ranch at Santa Paula, and one at Whittier, working at the latter place in conjunction with Mr. C. W. Leffingwell, Jr., and the Whittier Citrus Association. A large share of the credit for whatever good may have come from this work is due to the above companies, for furnishing fruit, labor and many facilities and conveniences for carrying on our experiments. The work has continued constantly since the beginning in the field, packing house and laboratory, most of the lemon packing houses of southern California contributing, in greater or less degree as called upon, to the progress of the work. It is with a feeling of more than ordinary appreciation that the writer acknowledges the support given to this investigation by the lemon industry of southern California. In the fall of 1905 a temporary laboratory was established at Whittier, through the courtesy of the Chamber of Commerce of that city, since which time most of the experi-

mental work has been done at that place, combined with extensive orchard and packing-house demonstrations in other sections. Most of the experimental and field work of the investigation has been carried out by Messrs. H. J. Ramsey, E. B. Babcock and C. O. Smith, especially the first named, while the study of the fungus in the laboratory has devolved largely upon Miss E. H. Smith.

METHODS OF GROWING AND HANDLING LEMONS.

It will be necessary to give a brief consideration to this subject for the better understanding of what is to follow. The lemon, like other citrus fruits, is an evergreen tree of semi-tropic habit, somewhat more easily affected by frost than the orange. As already stated the tree is peculiar in producing its fruit all the year round; that is to say, at almost any time in the year mature fruit, blossoms, and fruit in all stages of development may be found on the same tree. (See cover illustration.) Inasmuch as winter is the usual season of maturity of citrus fruits, a time when lemons are least in demand, this is a very valuable feature. There is a tendency to produce the bulk of the crop in winter and spring, especially in some varieties like the Lisbon, which feature is not at all desirable from the standpoint of the grower.

PICKING.

Lemons allowed to mature and color on the tree become overgrown, rough, misshapen, thick-skinned, of poor keeping quality and deficient in acid. One of the principal faults of the California lemon on the market has been due to irregular picking and allowing the fruit to get too old on the tree. In well-conducted orchards pickings are made once a month or at the longest every six weeks. The selection is made by means of a ring of 2¼ inches diameter (or at times a little more or less), all lemons which will not pass through the ring being picked. Smaller ones which have matured, colored and ceased growing are also taken. The most desirable fruit is that which is of moderate size, symmetrical shape and dark green color. The lemons are cut from the tree by means of clippers, placed in a sack carried by the picker, emptied into a field box and then carried to the packing house. In all these operations the greatest care is necessary not to cut or bruise the fruit in any manner.

WASHING.

It is at present the almost universal practice in California to wash all lemons as soon as they come from the orchard. The practice originated

from the necessity of washing decidedly dirty fruit, especially that which was affected by scale insects or the black, sooty fungus which follows their attacks. But the washing of even the cleanest fruit when green is so beneficial to its appearance after curing, giving it a gloss and finish not seen in the cleanest unwashed fruit, and the process is so inexpensive, that washing is now a routine process in lemon handling without regard to the original condition of the fruit. This washing is done in most of the houses with the machine shown in figure 1. This consists of a sheet iron tank of the shape shown, containing a circular arrangement of fixed brushes in the round portion, with an inner circle

FIG 1. Usual form of lemon washer.
(Photo by L. B. Williams.)

of brushes which revolves rapidly when the machine is running. The tank is filled with water up to the brushes, the fruit is dumped carefully into the portion shown in the foreground, and crowded along up into the circular portion where it enters the brushes, is carried around between them and then lifted by revolving arms onto the grading table, a moving belt on which the lemons are carried past the graders and distributed by them according to color—dark green, light green or yellow—into different compartments. This machine, in various modifications, is in almost universal use. A new washer gotten up by the Limoneira Company has a square wooden tank, brushes in the form of square troughs, and the grading table, all in a straight line. (Fig. 2.) The fruit is dumped into the tank, carried up by revolving arms and belts into the brushways, rolled and carried along between the brushes

by moving brushes which form the bottom, and so on out onto the moving belts to the graders. (Fig. 3.)

The severe washing and scrubbing to which much of the fruit has to

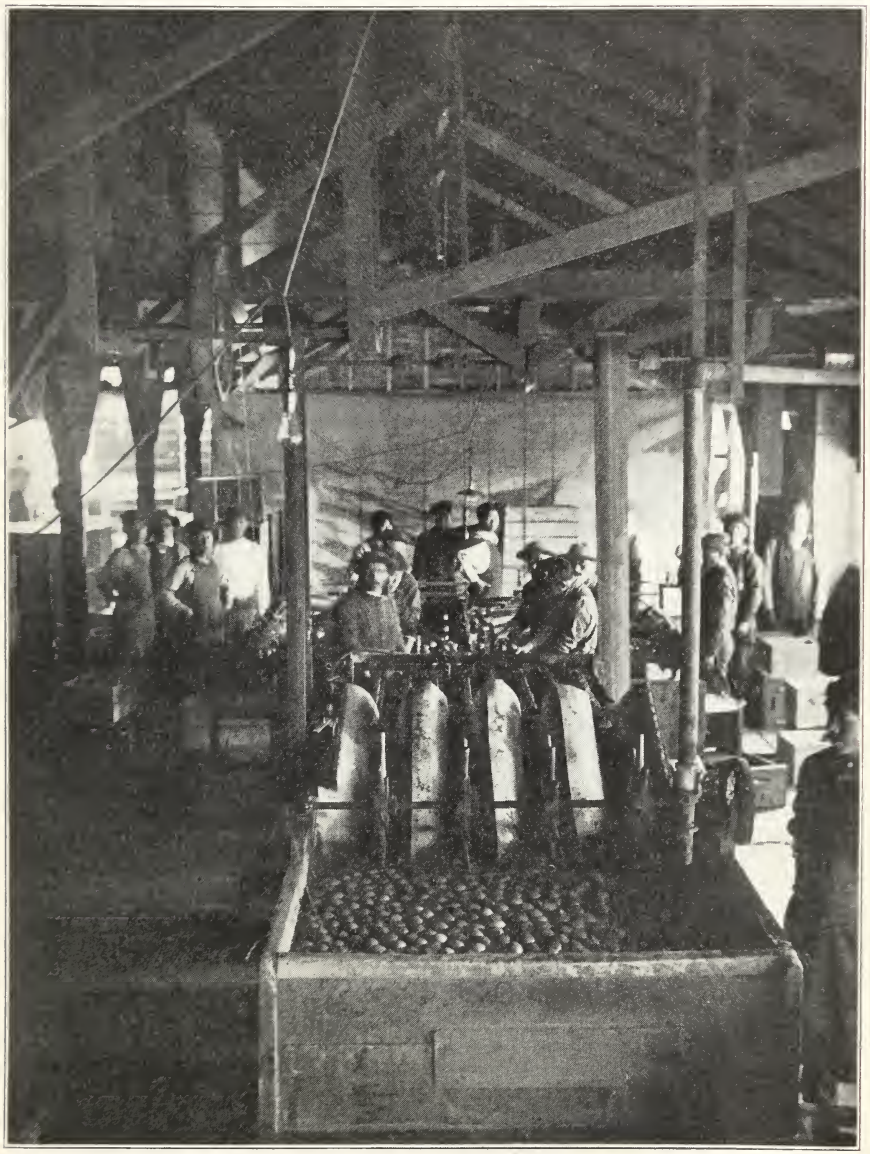

FIG 2. Limoneira washer. Tank end.

be subjected in certain districts is a very undesirable and largely unnecessary operation. The scale and smut, to remove which the washing is done, may be very completely controlled by systematic and

thorough fumigation, and the necessity of severe scrubbing thereby eliminated. The latter operation is expensive and can not fail to injure the fruit. The ordinary washing, however, even where nothing

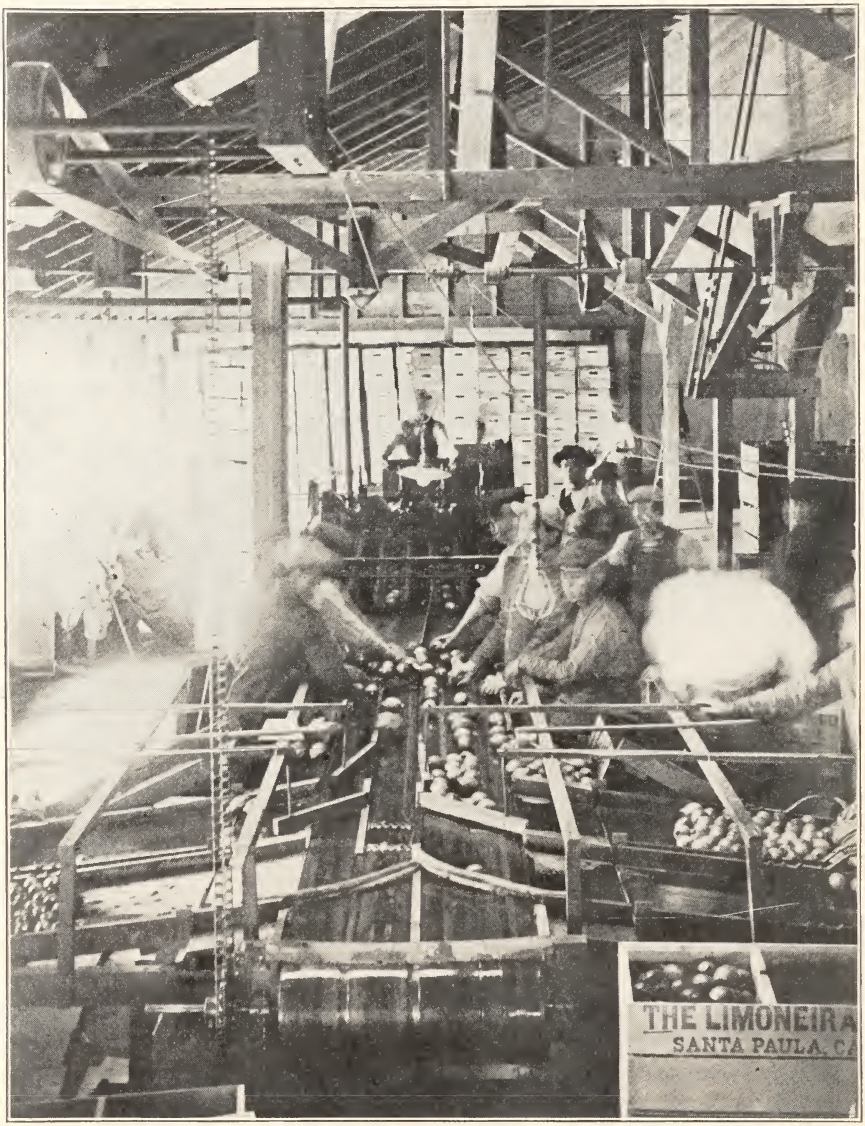

FIG. 3. Grading table of lemon washer.

more than an almost invisible dust is removed, is decidedly beneficial to the appearance of the cured fruit.

As it comes from the washer the fruit is placed at once into shipping boxes while still wet, and is then put away for curing.

CURING AND STORING.

The methods of holding lemons for curing and storing have been greatly improved in recent years. This is largely due to the development of the Limoneira system of tent-curing in open houses. The method consists in storing the fruit as soon as washed, usually in shipping boxes, in open-sided sheds exposed to the freest circulation of air and outdoor temperature. The boxes of fruit are stacked in square piles of about a carload each, each lot being covered with a canvas tent, as shown in figure 4. These tents consist of canvas tops and sides, the latter lacing together at the corners and rolling up on the sides. Under

FIG. 4. Packing lemons for shipment. Shows also curing tents. (Photo by L. B. Williams.)

this system each lot of fruit can be given its proper amount of ventilation, according to its condition and that of the atmosphere. The general object aimed at is to gradually dry out or cure the fruit, developing a juicy inside, thin, tough rind, yellow color, and smooth velvety surface. Too much moisture causes softening and decay; too little results in wilting and withering of the fruit and poor curing generally. The "button" or stem end which is left on the lemon in picking is the best indicator in the curing process. If proper conditions are maintained for gradual, uniform curing the button holds tightly to the fruit and does not drop off. If, on the other hand, the fruit is weakened by improper treatment the buttons begin to drop off and separate very easily and poor keeping quality results. Under certain conditions

shallow trays, like those seen in figure 4, are used for storage instead of boxes.

In the drier interior regions of southern California the tent system is not as satisfactory as nearer the coast, on account of too rapid drying of the fruit in summer, even with the tents closed continuously. For this reason some of the houses in that section, notably the Arlington Heights Fruit Company of Riverside and the Corona Lemon Company of Corona, are now using large basement rooms to a considerable extent for curing the fruit. These are arranged for ventilation and have various features adapted to their peculiar needs. In dry summer weather, even near the coast, it is usually necessary to cover the top boxes in the tent with papers to prevent excessive drying.

The condition of the fruit is carefully watched during curing, and if necessary it is taken down and sorted during the process to remove decay. This, however, should not ordinarily be necessary except on account of brown rot, a phase which will be considered later. It is desirable to handle the fruit as little as possible, as a certain amount of bruising and consequent decay is bound to result, even under the best conditions.

When fully cured the fruit is either shipped at once, or, if in good condition, may be held in storage in the tent for weeks or even months, according to market conditions.

PACKING.

When ready to ship the fruit is sorted from the storage boxes into trays according to quality. The packer, with his bench for the box and bunch of wrapping paper, then wraps each lemon in tissue paper and packs them uniformly in the boxes, picking out the particular size which he is packing as he goes along. (Fig. 4.) By thus selecting the sizes each box is made to contain a certain standard number of lemons, and is thereafter designated by the number and quality which it contains. The pack is uniform and systematic, the packer knowing just how many lemons he will put into the box and arranging them accordingly, selecting his size and putting a certain number in each tier. The packed boxes are taken to the nailer (see background, Fig. 4), who presses the cover down with a foot power press, nails it at the ends, and fastens an iron strap band about the center.

SHIPPING.

In forwarding the fruit to the Eastern markets, lemons are shipped in refrigerator cars in order to control the ventilation and maintain uniform temperature and moisture conditions. It has been thoroughly demonstrated, however, that with fruit properly cured and handled

the use of ice is not necessary in shipping lemons, and a number of houses are shipping the year round without it. Not only is the expense of icing saved (a comparatively small matter in proportion to the value of the shipment were icing desirable), but the fact that fruit will carry across the continent without ice is the strongest recommendation of its future keeping quality on the market. On the other hand, lemons which will not carry without ice will show decay sooner or later in any event. Icing, in other words, does not prevent, but simply postpones or temporarily checks decay. The individual shipper may be able to sell more of his poorly handled fruit by this means, but the whole industry is bound to suffer in reputation and market standing by the subsequent decay of this fruit after it reaches the retailer and consumer. Shipping successfully without ice is the standard which every progressive lemon-house manager will set for himself where this is not already accomplished.

A word should perhaps be added in favor of shipping under ice on long distance shipments in hot summer weather, in order to preserve the fresh, unwilted appearance of the fruit. This is not a matter of decay, but simply one of drying and shriveling, where the fruit may be three weeks or more in the car at a high temperature. Under such conditions the use of ice may often be advisable for the reasons described, but the shipper will do well to first demonstrate to his customers his ability to ship sound fruit under any conditions without the use of ice, and establish what is by far the most valuable asset in the lemon trade, a firm reputation for keeping quality.

THE BROWN ROT.

Were actual conditions which have obtained in the past few years portrayed in the above account of lemon handling, it would be necessary to insert in almost every sentence the clause, "Except for brown rot." This condition, as already intimated, has come to affect every phase and operation of the business, and has presented a very serious problem indeed to an industry already with its full share of complications.

WHAT BROWN ROT IS.

Brown rot is a certain form of decay of the lemon of an appearance and nature very characteristic to one familiar with it. The orange, pomelo and other citrus fruits are also affected, but not to the extent of the lemon, on account of the methods of handling the latter fruit. Brown rot in the packing house is distinguished most clearly by two features: its rapid spread in the fruit by contact, and its characteristic odor. In the ordinary blue mould, or *Penicillium* rot, the spread of the

decay from fruit to fruit in the box by contact is not common or abundant. Rather the condition shown in figure 5 occurs. Here is

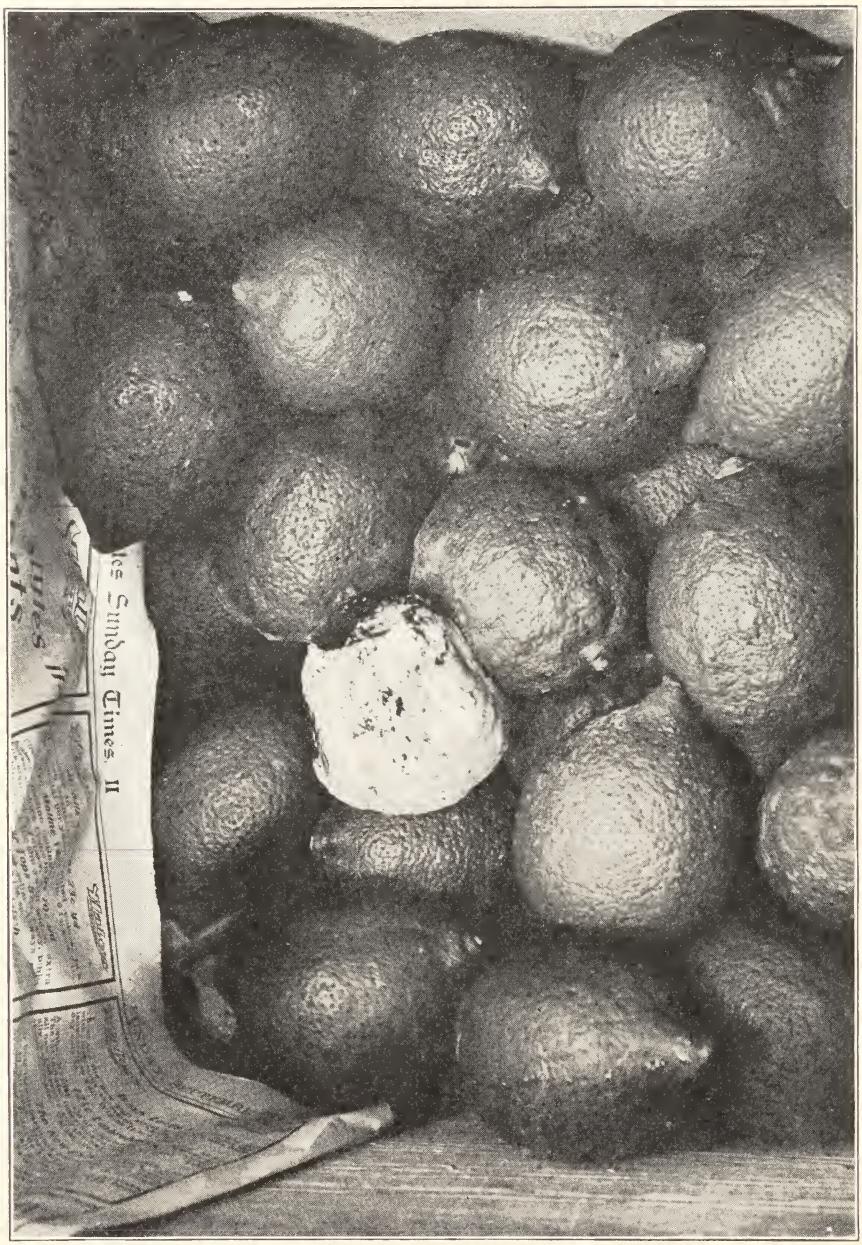

FIG. 5. Blue mould, or *Penicillium* rot, in box of lemons. One lemon affected without infecting others.

seen a box of lemons in which one has the blue mould, but this has completely rotted and melted down without infecting any of its neighbors,

though the latter are smeared with the spores of the fungus and the decayed remains of the lemon. This is the usual condition in well-handled fruit in respect to this fungus. A lemon here and there which presumably has been bruised takes the *Penicillium* rot, but no spread by contact occurs.

Figure 6 shows a typical condition in a box of lemons affected by brown rot. Starting with one lemon the decay rapidly spreads to those next to it, from these to the next and so on, until the whole box is gone. This is the most destructive form of brown rot, because of the fact that a single affected lemon in a box is almost certain to spread the rot to the whole half-box in a short time. The decay resulting from brown rot is a very filthy, putrid one. It is characterized further by the presence of innumerable small flies which invariably collect in swarms about such lemons, and breed in the decaying fruit. The maggots of these flies contribute very largely to the complete decomposition which takes place in affected lemons.

The odor of brown rot in citrus fruit is most characteristic, and to one familiar with it serves to detect even a very small amount of rot in a large amount of fruit. A few affected lemons will betray the rot in a tent, while at a time of considerable prevalence the whole house smells of it. This odor is not a particularly repugnant one, but has a characteristic rancidity and penetration, originating presumably in a fatty acid produced in the decomposition of the oil in the rind of the fruit. The little flies mentioned above seem quick to detect this odor, and the first cases of brown rot in a tent of fruit are sufficient to attract these insects in a manner which is not the case with other forms of decay.

Brown rot, then, is distinguished from blue-mould rot in a practical way by its rapid spread, peculiar odor and the presence of numerous small flies on the boxes containing affected fruit, even in closed tents. The experienced man seeking to detect the rot in his house goes through the tents, jarring the boxes for the flies and sniffing here and there for the odor. By these means he will detect even a surprisingly small amount of the trouble.

OCCURRENCE OF BROWN ROT IN THE ORCHARD.

Little has been said as yet as to the occurrence of this trouble in the orchard. It is common there in affected regions, however, on oranges, pomelos, tangerines, etc., as well as on lemons. It is indeed on orchard-affected fruit that we see the trouble more commonly in its pure condition, unmixed with other forms of decay. Our colored frontispiece shows typically brown rot-affected lemons from the orchard. Such fruit is found lying on the ground beneath

the trees, and also still hanging on the tree, usually within two feet of the ground, but occasionally higher. It occurs only in wet weather

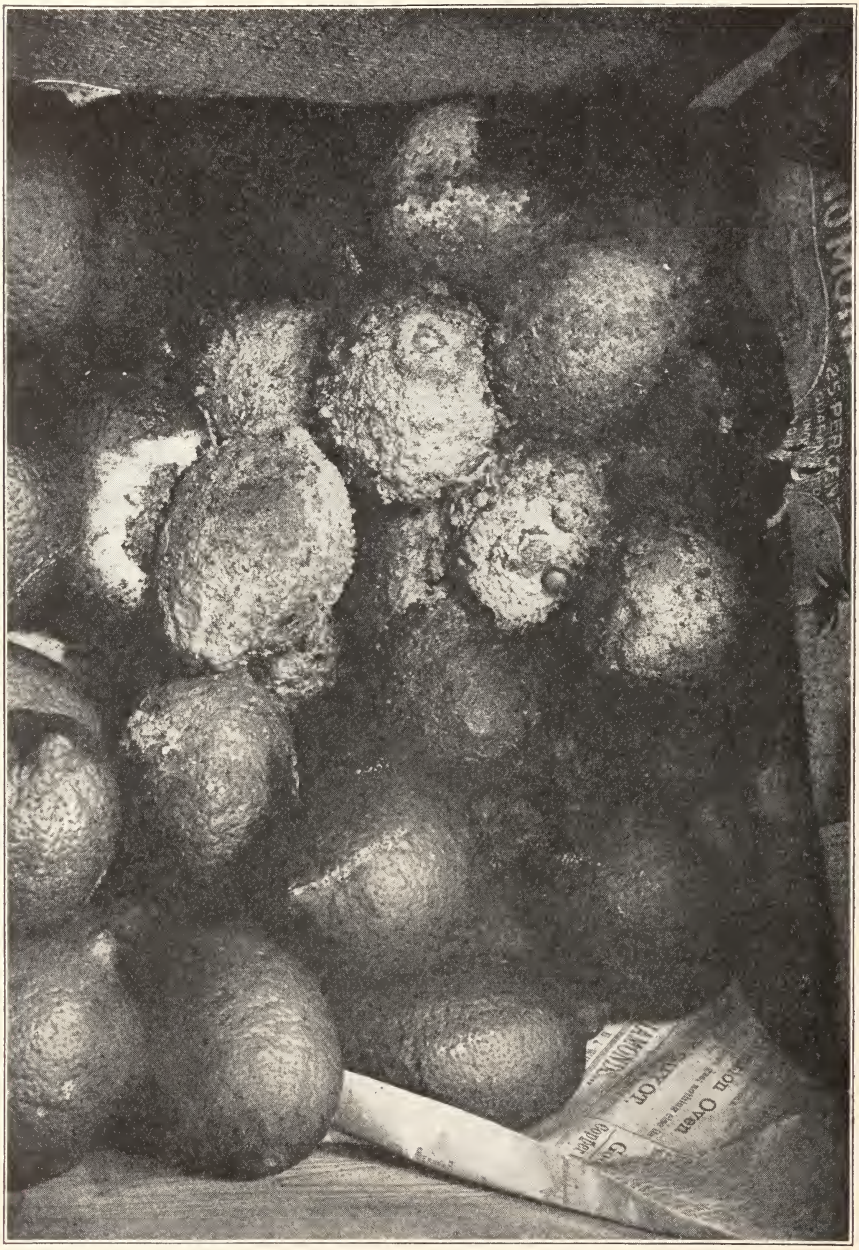

FIG. 6. Brown rot in box of lemons. Abundant spread by contact.

or on low ground after irrigation, always more abundantly on the lower, heavier soils with more moisture, and has become extremely

abundant in most of our lemon orchards during the winter and spring season. On oranges the rot is commonly seen in the orchard only on fruit lying on or close to the ground in very wet places. The rot is particularly liable to occur on trees standing in a "wash," in the orchard, where drainage water runs over the surface and keeps the ground beneath the trees bare, moist, and covered with sediment. It is easily seen that a considerable amount of fruit is affected while still on the tree and then falls to the ground. In this way many lemons are lost in bad cases, as in figure 7, where the fallen brown rot-affected fruit can be seen on the ground. Fully a box of fruit to the tree is lost

FIG. 7. Brown rot in the orchard. Fallen lemons affected over bare, uncultivated ground.

in some orchards every winter in this way. The affected fruit is not badly decayed, that is, it is not softened or disintegrated to any extent. The rind is still firm and the tissue sound. No appearance of mould or fungus is seen upon the surface. There is simply a slight discoloration, gradually extending from a center, of a light brownish and slightly purple color, not extremely prominent, but showing light on dark green fruit and dark on that which is yellow. Lemons of any size may be found affected on the tree, from the very smallest to those which are mature. The decay is not in any sense one of old or weakened fruit, but affects the youngest and most thrifty to an equal extent. The characteristic odor is distinguishable from the very first, and is practically identical in the different citrus fruits.

OCCURRENCE OF BROWN ROT IN THE PACKING HOUSE.

At times of brown-rot prevalence there is always more or less orchard-affected fruit which escapes the pickers and is brought into the house.

FIG. 8. Lemons with brown rot from boxes showing white growth of the *Pythiacystis* fungus.

This has the same appearance as that seen in the orchard and is mostly thrown out at the washer by those through whose hands the fruit goes.

FIG. 9. Contact infection by brown-rot fungus.

If fruit in which brown rot is developing be examined after about a week's storage, the condition shown in figure 8 will be found. On the

surface of affected lemons a white, delicate, quite abundant mould develops, and it is natural to conclude that it is by the growth of this mould that the contact infection and spread take place. Where an affected lemon touches another the growth of the mould from fruit to fruit, as in figure 9, is evident, and in advanced cases, like figure 6, the same white mould can be seen advancing onto new fruit. Affected fruit in the packing house soon becomes covered with the blue-mould fungus, which obscures any other characteristics, but when new the brown rot has a very distinct appearance from any other form of decay.

The worst feature of the rot in the house is the frequent development of the trouble in great abundance in fruit which showed no sign of the

FIG. 10. Lemons infected with brown rot by soaking in infected water.

rot when washed and stored. Granting that an occasional lemon with orchard infection may escape the men at the washer and go into the tent, it is still a fact that by far the largest amount of brown rot in the tent develops in fruit which was perfectly green and sound when put up. Early in this work the writer has carefully watched, for hours at a time, the fruit coming from the washer, finding nothing but the finest, dark green sound lemons, and on examining the same fruit later found perhaps several affected lemons in each of a majority of the boxes in the tent. This, with the rapid spread by contact which begins as soon as the rot develops, has been the most serious and discouraging feature of the whole situation.

The occurrence of brown rot in this manner begins to show, under

average conditions, in about five days to a week from the time of washing and storing. The first sign of the rot is a dark, sunken spot on the surface of the lemon, like one of the spots shown on the fruit in figure 10. Not more than one spot on a lemon is commonly seen in ordinary cases. This spot rapidly spreads, a discolored area develops on the lemon, and, if there is moisture enough, the white mould appears on the surface. This produces the stage shown in figure 8, or that of the colored frontispiece if there is not moisture enough to develop the surface mould. Contact infection of more fruit begins at once, and the conditions shown in figures 8 and 6 result. Lemons infected by contact also show at first a dark colored spot at the point of infection. At the very first of infection of this sort the delicate white mould can be seen attaching itself to the lemon, growing from the one previously affected, and in many cases this can be wiped off, leaving the fruit apparently intact. In the majority of cases, however, and practically always after the dark spot has appeared, lemons on which the fungus has begun to grow develop the rot and can not be saved.

THE CAUSE OF THE BROWN ROT.

The brown rot is caused by a fungus, that which produces the white mould seen on the surface of affected fruit, as in figures 8 and 9. This fungus has proved to be a hitherto unknown form, and has been named *Pythiacystis citrophthora.** It is an active parasite of citrus fruit, readily causing infection of green growing fruit by means of its spores or by growth of the fungus itself from one fruit to another when in contact.

DISCOVERY AND IDENTIFICATION OF THE PYTHIACYSTIS FUNGUS AS THE CAUSE OF BROWN ROT.

In a case of this sort it is not sufficient to simply find a fungus of some kind growing in connection with affected fruit, in order to positively identify the cause of the trouble. For the strictest proof in this respect the organism must first be found to occur regularly in affected tissues; it must, if possible, be isolated and grown in pure cultures, and above all it is necessary to produce the typical disease artificially by inoculating healthy material with the suspected organism in pure condition. When this has been accomplished we are safe in assuming that we have found the cause of the trouble. In the case of the brown rot, where the cause was entirely unknown at the beginning of the investigation, the probability was quite strong that the white-mould fungus which appeared on the fruit was the cause of the rot. On

*Botanical Gazette 42: 215-221, Sept. 1906.

lemons free from other fungi it could plainly be seen that this mould was distinct from *Penicillium*, and the occurrence of contact infection

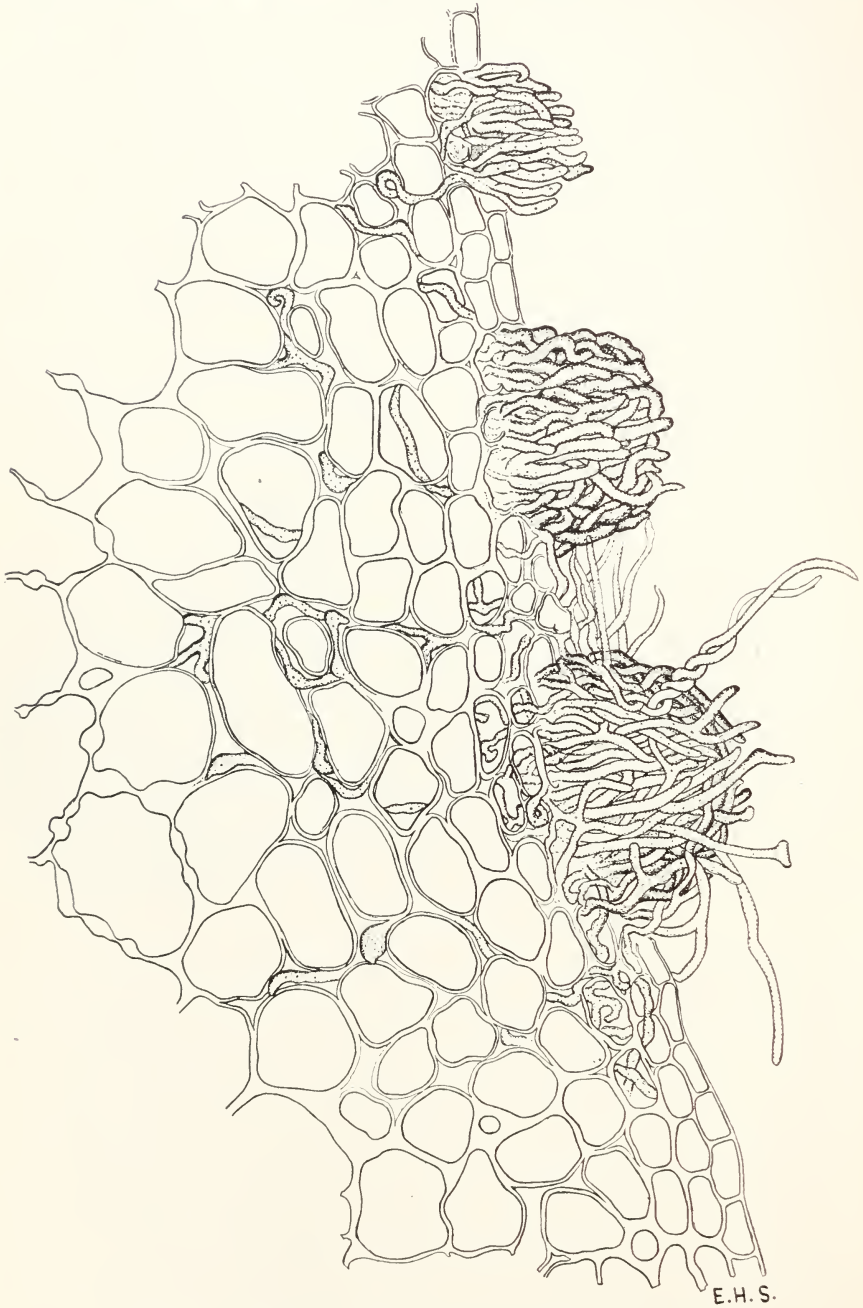

FIG. 11. Section of lemon rind, showing brown-rot fungus.

like that shown in figure 9 left little doubt that this fungus was the cause of the spread of the trouble. Examined with the microscope it

was found that the tissue of affected lemons, even when no mould was visible upon the surface, was full of the filaments of a fungus, and when kept in a moist chamber the typical mould at once developed upon the surface of such fruit. (Fig. 11.)

Two significant facts were discovered early in the investigation. First, that if affected lemons were soaked in a pail of water for a few hours, then taken out and good fruit put in for a similar time, the latter would invariably become badly infected with the typical rot. (See experiments I-19, I-24, I-31, I-51, and checks in many others.) It was also found that if the water thus infected was boiled before the good lemons were put in, no infection resulted. (Experiment I-24.) This was satisfactory evidence that some living organism was causing the brown rot. Second, it was found that if affected lemons were laid on moist soil or buried just beneath the surface, the same white mould soon appeared upon the soil. Good lemons laid on the same ground soon took the rot. (Experiments I-30, I-33, I-66, I-83.) All then that remained was to grow this fungus in pure cultures, identify it and produce the rot from cultures. This has been accomplished. After securing a pure growth of the fungus in culture media in flasks, it was found that by emptying such a culture into the pail of water instead of soaking affected lemons in it, typical brown rot resulted in lemons soaked in the water. (II-10A.) This completed the chain of evidence as to the cause of the trouble. The fungus, after much technical study, proved to be a form not previously known and was given the above scientific name and described in the journal cited.

NATURE OF THE BROWN-ROT FUNGUS.

Pythiacystis citrophthora is apparently in its original nature a harmless and inconspicuous fungus inhabiting moist soils and water. But for its acquirement of this remarkable parasitism of the lemon it might very likely have never been discovered or attracted any more attention than many other microscopic, unimportant moulds which live in the soil.

The Fungus on the Fruit.—As it occurs in the form of the white mould seen on affected lemons and causing contact infection, the most important feature of the fungus is the fact that it is entirely sterile, developing no spores of any sort. The fungus in the tissues of the lemon and on the surface consists simply of a mass of filaments of rapid, vigorous growth when supplied with moisture, but no spores. This is a most important fact. In a case like that of the blue-mould fungus the surface of affected fruit is covered with a fine dust which is composed of inconceivable numbers of the spores which propagate

the organism. The air, the dust, every box, lemon and part of the packing house carries an abundance of these spores to start the growth of the fungus when favorable conditions occur. Were this so with the brown-rot organism the case would indeed be serious, since the ability of the latter to attack sound fruit is so much greater than that of *Penicillium*. But this is not the fact. The fungus on the fruit develops no spores, and there is absolutely no more infection of lemons after they leave the washer except by contact. The fungus simply grows from one lemon to another, starting from those which were already infected when put away, and no new lemons become infected except in this way. Many affected lemons may go into the tent in which the rot has not developed enough to show, but we have absolutely proven that the fungus produces no spores in the packing house and does not have the slightest means of spreading there except by vegetative growth from lemon to lemon. It should not, however, be understood that, even by the closest examination, all affected lemons can be detected as they come from the orchard or washer. One of the worst features of the whole situation has been the abundant rot which often starts in the tent, in fruit which was apparently in the soundest, finest possible condition when put away. Such occurrences result from infection before the fruit is stored, but the rot does not develop enough to show to the eye for several days.

Some further observations are to be noted in regard to this fungus, in addition to the description already published.* While the characteristics there given have since been repeatedly confirmed, we may modify one clause in the description to the following extent. The original reads, "Aquatic mycelium typically sterile, with occasional conidia or sporangia." Sporangia have since been found to develop in water or liquid cultures rather profusely in many instances when a week or two old. In these cases, however, the zoöspores seldom develop normally, the protoplasmic contents usually emptying through the pore without division, or remaining within the sporangium.

The fungus grown on moist soil never fails to produce normal sporangia, which, when placed upon a microscopic slide, rapidly eject their swarmspores. That spores are ejected in the soil is evident from the empty sporangia on removal. In soil too dry to produce swarming the sporangia retain their vitality for a certain period after maturity, but after remaining in this condition for about a week they fail to function, even after prolonged soaking.

As stated in the former paper, dilute prune juice appears to be the best medium for procuring the vegetative stage of the fungus, in which it develops as a vigorous, profusely branched, continuous, globular mass of mycelium, suspended in the liquid. (See Fig. 1 in paper above quoted.) A quick and sure way to obtain sporangia is to take a bit of mycelium from a prune culture and place in water in a shallow dish. Within 48 hours the fungus fringes out at the edges of the mass, changing from the thick vegetative type to slender threads and sporangiophores.

Almost limitless variations from the typical shape of sporangia are to be found in soil and water cultures. (Fig. 12.) All the types illustrated have been found in soil, though most with less frequency than in water. Sporangia with two or three pores (Fig. 12, B, C, D) are common, though frequently only one of these opens for

*See Botanical Gazette 42: 215-221, Sept. 1906.

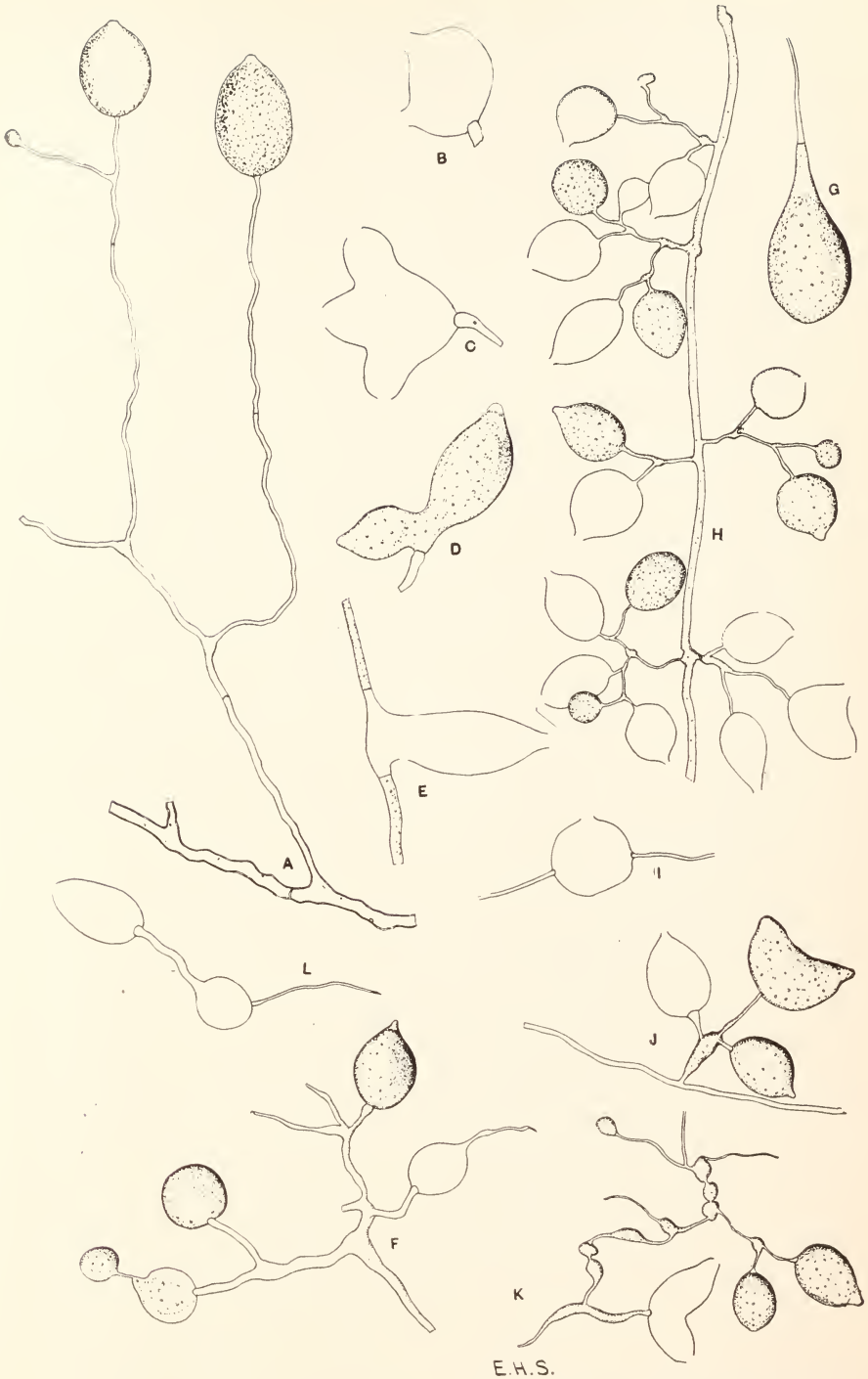

FIG. 12. Sporangiophores and sporangia of *Pythiacystis,* showing range of form.

the passage of the spores. Intercalary sporangia are rarely found (Fig. 12, E and I) with all gradations between this and the long water sporangiophores as figured in A, figure 12. The length of some of the latter is extreme, especially when developed from affected lemons in deep water, one measured being over 1.6 mm. In all media a slight swelling at the base of the sporangiophore is quite characteristic, which may be so developed as to present the appearance of a series of nerve ganglia. (See K, Fig. 12 and others.) The manner in which the sporangium joins the sporangiophore varies widely. In many cases the sporangiophore widens toward the junction, which we at first took to be characteristic. (Fig. 15.) In the majority of later cultures, however, the sporangiophore remains of uniform width at the tip.

In rare instances the sporangiophore has been seen to grow on into the empty sporangium from the point of insertion, as De Bary records for some species of Pythium (Fig. 13, K), but never to develop further than as figured.

There is the most gradual gradation possible here between De Bary's "conidia" and the sporangia with zoöspores. (Fig. 13, D-J.) The two organs are apparently identical in development up to a point where certain conditions cause them in the case of conidia to germinate from the pore (which is always formed), while other conditions previously described bring about a rounding off of the protoplasm into zoöspores. A conidium on germinating will sometimes produce a true sporangium within a few microns of its tip. (Fig. 12, F and L.) Most of the figures of germinating conidia were drawn from those which had developed on an affected lemon floating in water. It is under these conditions that the conidia develop most freely, the sporangia being seldom found. In pure cultures in tap or distilled water, if at all fertile, sporangia are more commonly developed than conidia, most of the latter, however, being imperfect in their formation of swarmspores as before stated.

In the search for the reproductive organs of *Pythiacystis* the numerous sprouts which are at first more or less globular have been rather misleading. (Fig. 13, A-C.) Innumerable variations as to shape are found among these, especially in old water cultures. From old seemingly dead mycelium new branches will push out in this way after a period of inaction, without a change of medium, though the growth in this case is spindling and not long maintained.

As yet no evidence has been found of a sexual stage in the life history of the fungus. Various means have been tried in the attempt to develop this stage, and a careful watch kept on the fungus in its natural environment. We have satisfied ourselves that it does not occur as an economic or otherwise important factor, or that if present at all it does not assist the fungus to live through periods of drought. It is interesting to note in this connection that on several of the older prune cultures a crusty white layer developed, one-eighth inch or less in thickness, with very much the appearance and brittleness of lard which has cooled on the surface of a liquid. At first this was thought to be an impurity, but a layer of the same kind has since been formed on cultures known to be pure. The formation has been noted to some extent. After the flask becomes filled with the fungus, which then comes to the surface of the liquid, a thin surface scum is formed which grows up slightly on the sides of the flask. This is a network of slender mycelial threads, on which tight balls of mycelium develop, with a beginning much like the so-called bud formation. (Fig. 13, B.) The completed layer is a close, sclerotium-like mass of mycelium. We shall investigate further along this line.

As previously stated, this fungus grows only on very moist media, most of our work being done with liquid or wet soil cultures. If placed on a solid medium, such as agar-agar or potato agar, the fungus may spread through the medium to some extent, potato agar seeming to be the most favorable of the solid media. In this the organism will occasionally produce sporangia of a degenerate type.

The Mode of Spore Formation and Infection.—It was particularly important in this investigation to determine accurately the manner and place in which the primary infection of the fruit takes place. Such

FIG. 13. Vegetative bud formation and conidia of *Pythiacystis*.

knowledge must underlie any logical attempt to devise means for checking the occurrence of brown rot. Fortunately, this has been accomplished, and the results of the investigation in this direction have proven of very great practical value. It has been found, as will be explained, that there are two modes of infection, in the orchard and in the washer, and methods have been devised by which each of these may be prevented, or controlled to a very large extent.

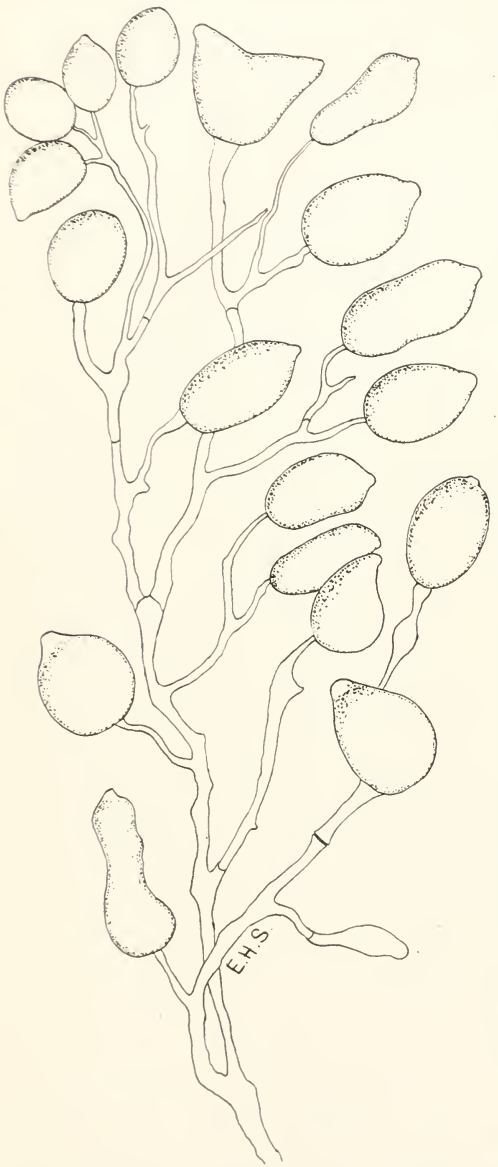

FIG. 14. Brown-rot fungus, with sporangia, in wet soil. After Smith & Smith, Bot Gaz., loc. cit.

ORCHARD INFECTION.

The fact has already been mentioned that an affected lemon allowed to lie on the ground soon spreads the fungus to the soil and makes it infectious to sound fruit laid upon the surface. This demonstrates that the fungus is able to live on the soil and cause infection by contact, just as it grows from one lemon to another. It leads further to the supposition that the soil of the orchard must be a breeding place of brown rot, on account of the large number of affected lemons which lie and decay on the ground under the trees.

Further than this, however, we have found that it is in the soil that the spores of the fungus are produced, and that this is the original source of all the infection of lemons except that which takes place by contact.

The *Pythiacystis* fungus is by nature a soil dweller. Its growth on the lemon is, in a sense, an abnormal condition. Its spores, as in other fungi of the same class, are produced only in abundant moisture, a

condition which is not found on the surface of a lemon in air. Laying an affected lemon on wet soil, or on moist paper, or placing a mass of the fungus from a culture in a similar situation, we soon find the spore condition developed in great abundance. This is of the rather complicated type known as *sporangia* with *zoöspores*. The fungus grows out into the soil producing the visible mould on the surface, and amongst this are found numerous rounded bodies of microscopic size, which are the spores or sporangia. (Fig. 14.) Ordinary fungus

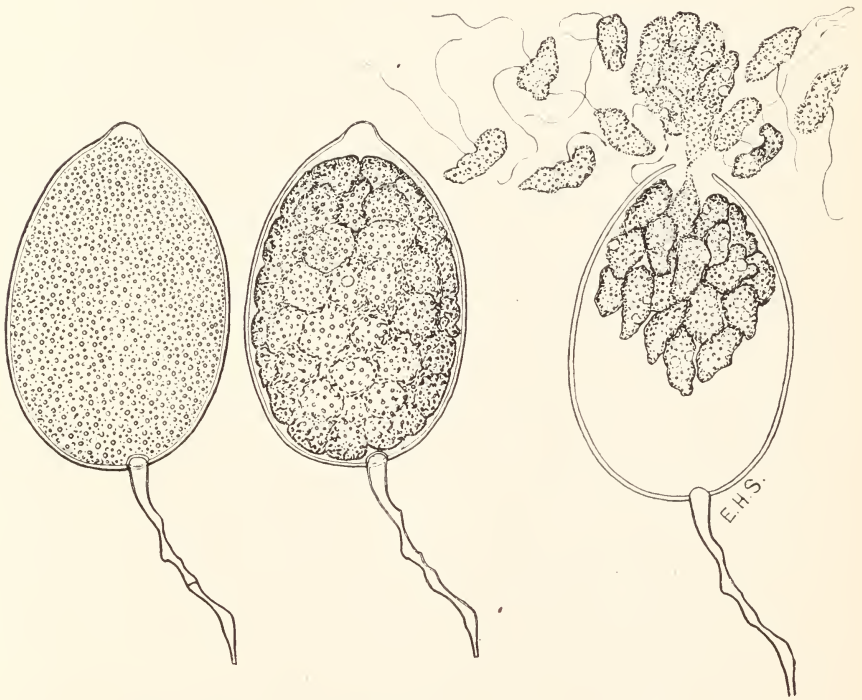

FIG. 15. Showing development of swarmspores from sporangia in the brown-rot fungus. In the sporangium on the right the swimming swarmspores are escaping. After Smith & Smith, Bot. Gaz., loc. sit.

spores are simply little round bodies which germinate by sending out a sprout wherever they happen to be lying, if moisture and other favorable conditions are present. These sporangia of fungi of this type, however, have a different process. They develop only when in water. When proper conditions come, the inside of each one divides into about thirty smaller spores or zoöspores. These minute bodies are of a nature more animal than vegetable in their appearance and action. Each is provided with two fine, hair-like appendages which lash vigorously about in water and enable the spore to swim about with all the appearance and activity of animal life. (Fig. 15.) They soon come to rest, lose their power of movement, and, if conditions are right, each

one germinates, sending out a sprout which grows into a filament and produces the brown-rot fungus again. (Fig. 16.)

This, then, is what occurs in the orchard. Lemons affected with brown rot fall to the ground. The fungus grows out into the soil and produces its mycelium or mould growth, which, when there is abundant moisture, as in wet weather, develops great numbers of the primary

FIG. 16. Germinating swarmspores about six hours after coming to rest.

spores or sporangia among the particles of the soil. These lie until they become decidedly wet, then break up internally into a large number of swimming zoöspores, which move about freely in whatever moisture is present, finally coming to rest and germinating to produce the fungus again.

It is then not difficult to conceive of what happens in regard to infection of lemons on the tree with brown rot. With each succeeding occurrence of the disease the soil becomes more and more infested with the fungus. In wet weather and particularly in low, wet ground, the

organism is active in the soil and develops a great abundance of sporangia. These lie mixed with the soil, forming a part of the finer surface portion. In heavy rain they spatter up with the dirt onto the

FIG. 17. Experiment in preventing brown rot by covering ground under tree with burlap.

lower limbs and fruit of the tree. Zoöspores are formed in the moisture, occasionally on the surface of lemons, and these germinate and produce infection. Thus a certain amount of rot occurs on the tree during the wet season, and on account of the nature of the process it is confined mostly to the lower portion of the tree.

It is very easy to demonstrate that the soil under the trees in infected

orchards is full of infection. This was determined in our investigation by soaking good lemons in water containing soil from such places. In the brown-rot season a small amount of soil taken from under a tree where the fruit is affected, and placed in a bucket of water, will cause abundant infection of almost every lemon which is thereafter soaked in the water. Such soil, indeed, has been found to be the most favorable material for infection and disinfection experiments, producing 100% of brown rot almost invariably, and a large number of separate infections on each lemon, as in figure 10. (Experiments I-83, I-96, and all later disinfection experiments.)

For a practical demonstration of the fact that infection by brown rot does come from the ground under the tree in the manner described, the experiment illustrated in figure 17 is quite convincing. In this case four representative trees in an orchard badly affected with the rot were chosen, and a covering of burlap stretched under each tree on a wooden frame about six inches from the ground. This was in February, when the rot was very prevalent on all the trees chosen for the experiment and much of the bottom fruit had already been lost. A number of similar trees were chosen as checks. All lemons affected with brown rot were picked from all the trees in the experiment and from the ground beneath them. Ten days later all the affected fruit was again removed, in order to get all that had been infected before the experiment started. Had the experiment been begun before the large amount of fruit removed in these two pickings had become infected, the results would have been even more striking. During the period from February 8 to April 15 two brown-rot lemons developed on each of two of the burlaped trees, none on the other two. In each case these two lemons were some which hung low, out over the edge of the burlap, and were not protected from the ground. No lemons became affected over the burlap, and none at all on the other two trees. Thirty-nine check trees surrounding the others (being all of which records were kept) showed brown-rot lemons, respectively, as follows: 8, 11, 14, 10, 14, 15, 12, 28, 19, 16, 19, 21, 21, 19, 9, 33, 10, 15, 12, 14, 24, 23, 17, 11, 20, 26, 38, 17, 4, 31, 26, 33, 31, 20, 27, 27, 33, 46, 53, or an average of over 20 per tree. It should also be noted that the amount of brown rot on these check trees was decidedly reduced by the greater or less covering of the soil under them with cover crop and weeds. In every case those showing a comparatively small amount of rot had a considerable amount of soil covering, which had an effect of the same nature as that of the burlap in preventing infection. Trees under which the ground was nearly bare all showed from 30 to 50 brown rots, and also had lost very heavily before the experiment began.

This experiment substantiates the statement that orchard infection with brown rot comes entirely from the ground.

INFECTION IN THE WASHER.

It has already been stated that one of the most puzzling features of the brown-rot situation has been the great prevalence of the rot in the curing tent, in fruit which when put up seemed perfectly sound and free from the slightest sign of decay. It is admitted that some orchard-infected lemons must get into the tents when the trouble is abundant. This could hardly be otherwise, when lemons in all stages of infection come in, with the affected spots not particularly conspicuous and some of them very small. A great deal is thrown out by the men at the washer, but naturally some escape them. Without question, too, there are times at which a large amount of fruit is brought from badly infested orchards which has been so recently infected that it does not show the presence of the rot to the eye at all. This fruit looks perfectly sound, and only after several days in the tent does the fungus develop enough to show itself. This often happens.

But a common, and indeed the worst, occurrence of brown rot can not be accounted for in this way. At times, infection and spread by contact develop in the tents when no rot whatever is showing in the orchard, usually in early summer after the ordinary brown-rot season is over, and in amounts out of all proportion to the apparent orchard occurrence, whatever the season. This has proved to be infection from the washer, and we have demonstrated beyond a doubt that thousands of boxes of sound lemons have been infected with brown rot in the washing machine in the packing houses, that the rot has been enormously spread in this way, and that in this lies the principal, most general, and most easily prevented source of infection by brown rot.

In dumping the fruit into the washer tank, box and all are submerged, if possible, in order to float the lemons into the water gently. With them go leaves, twigs, blossoms, the dust and dirt of the orchard and considerable soil which clings to the bottom of the boxes where they have rested on the ground. At the end of a day's run there is a large amount of sediment of this sort in the bottom of the tank. Knowing the nature and habitat of the fungus, as explained above, it is easy to see how the wash tank may become a prolific source of infection of sound fruit with brown rot. The orchard soil and dust are full of the sporangia of the fungus. When dumped into the washer zoöspores are produced in great abundance, become attached to the lemons, and start an infection which does not become visible until several days later, after the fruit has been stored. One of the chief problems early in the investigation was to discover how the wash water became infected, since the fact that it was infectious was soon discovered. It had been demonstrated that affected lemons soaked in water for some little time made such water infectious, but the small number of affected lemons which get into the washer and the short time that they stay there seemed to preclude any general

infection from that source. The discovery of the spore-producing habit of the fungus in the orchard soil first revealed the real manner by which the spores of brown rot get into the washer.

Definite experiments have proven that fruit can and does become infected in the tank in this way. By putting a shovelful of orchard soil into the 1,000-gallon tank of a washer, and then running lemons through in the ordinary way for washing, it was found that from 10% to 40% of the fruit took the rot. (As to the infectiousness of the ordinary wash water, see experiments I-12, I-36, II-3 and II-16. On the infection of the washer with soil, see IV-1, IV-11, IV-14 and several following. Also Fig. 25.)

Not only does the fungus become introduced from the orchard into the washer in the manner described, keeping the water continually infected, but experiments have shown that *Pythiacystis* may also come to inhabit the machine permanently if not destroyed by thorough cleaning or disinfection. It has seemed in many cases as though the fungus was being bred in the washer itself, rather than being continually introduced anew with each day's run. This condition has been suggested especially by the fact that the rot would suddenly and completely stop appearing in the fruit after a machine had been very thoroughly cleaned, dried out for some time, and painted inside. Again, fruit of the same lot would rot much more badly when washed in one washer than in another. To test this we have experimented by soaking various parts of the machine in water with sound lemons. Besides the metal tank, solid frame work and brushes, these washing machines contain various pieces of cloth, sheepskin and other padding to protect the fruit from bruising. Soaking this padding in water with good lemons, we have been able to produce brown rot in considerably large amounts in the fruit. This therefore indicates that the fungus is able to grow and propagate in the machine more or less, attaching itself to materials like those mentioned above which are favorable for its development. The brushes also become quite foul, and accumulate large amounts of material which would permit the growth of *Pythiacystis*. The whole operation of washing lemons under ordinary conditions is peculiarly favorable to infection with a fungus of this sort. (See experiment I-41 on infection from washer padding.)

THE CONTROL OF BROWN ROT.

To the practical lemon man the all-important question is, How shall we prevent or control this trouble in an economical and practical manner? This problem we have attempted to solve as fully as that of the nature and habits of the organism causing the brown rot, but the former depends upon the latter.

With our present complete knowledge of the modes of infection by brown rot, it is not difficult to see the lines along which we must proceed to look for methods of completely checking the trouble. We have seen in the above account of the nature of the rot that there are three very distinct sources or places of infection of lemons, and no more. These are: in the orchard, in the washer, and by contact. Upon the extent to which the fruit can be protected from infection at these three points depends absolutely the extent to which the rot may be eliminated from our lemons.

CONTROL IN THE ORCHARD.

Since the infection with brown rot, or the spores of the fungus which produce it, originates primarily in the soil of the orchard, it is self-evident that if we could exterminate the fungus at that point we would succeed in checking the rot absolutely by that means alone. If this be not practical in its entirety, it is at least possible to aid very materially in eliminating brown rot by orchard methods. This is to be accomplished, according to our results, by two general methods: first, by checking the development of the fungus in the soil; second, by preventing the infection of the fruit on the tree by spores from the ground, by chemical, cultural, or other means. In connection with this we have made considerable study of the life and distribution of the fungus in the soil. The organism is doubtless a native of our soils in wet ground, but might not be expected to be common or easily found under ordinary circumstances. We have never succeeded in finding it in any soil outside of citrus orchards. Our method of soil testing for this fungus has been to place in a bucket of water about a pint of the soil to be tested. Sound lemons were then soaked in the water for various lengths of time, then put away in a box in a curing tent. With soil where the fungus is abundant every lemon will in a week's time show very numerous infections, as in figure 10. According as the fungus is less abundant less infection will result. A very small amount of badly infested soil is sufficient to produce very abundant infection. *Pythiacystis* is most abundant in the soil directly under the trees, where the fungus is maintained by the affected fruit which falls each year upon the soil. The distribution or extent of the occurrence of the fungus in the soil away from the trees is governed entirely by moisture conditions, and in fact its whole development depends upon a large amount of moisture, and too much dryness is fatal to it. In the wet winter season soil taken from anywhere in the orchard in affected regions is highly infectious and full of the fungus. The same is true of soil which washes from the orchard, even where it is carried for considerable distances. In depth the soil becomes infested for at least 4½ feet, as soil down to that distance has been found to infect lemons. (For experiments on infec-

tiousness of soil from different depths, locations, etc., see I-83, I-96, IV-17, IV-28, IV-30, IV-31, IV-32, V-6, V-7.) As the dry summer comes on the soil away from or between the trees gradually loses its infectiousness, and after it has thoroughly dried out lemons may be soaked in water with any amount of it without producing brown rot. Samples of the most infectious soil taken in winter and allowed to dry show the same change. A soil which produces 100% of infection and very numerous infections on every lemon, becomes entirely innocuous after several weeks' drying. (Experiments I-80, I-87.)

In the orchard the activity and distribution of the fungus keep on narrowing and lessening with conditions of increasing dryness, until, in soils which are not kept too wet by irrigation, the organism may die out altogether on the surface. Similarly in depth the fungus recedes with the moisture, leaving the upper soil, and remaining alive only farther down where there is more dampness. Near ditches and flumes, where the ground keeps wet, or in low ground where irrigation floods the surface, the fungus often remains active all summer and may produce infection of fruit on the trees in such situations. In the fall, when rain occurs again, *Pythiacystis* again begins to spread. The soil becomes infectious first on the northwest side of the trees, where there are most shade and moisture. Soil from this location always produces infection before that from the other side of the tree or that between the trees has any effect. The rot also begins to show first on fruit on the tree at this point. As more rains occur and the soil becomes saturated with moisture, more and more rot occurs on the trees on all sides, the affected fruit falls to the ground and is scattered about, rains wash the surface soil through the orchard, the fungus grows vigorously in the wet ground, and soon the whole body of soil becomes infested and infectious again.

After working out quite fully these features in the life history of our fungus, with the results described, it seemed very clear that in orchard practice anything which would tend to stir up and dry out the surface soil in summer would be of practical value in checking brown rot. We therefore have urged the practice of thorough summer cultivation, *especially under the tree,* and have made extensive observations as to the results of this practice. In most lemon orchards no attempt whatever is made to cultivate the ground beneath the trees. The plowing and cultivation go up and down and across the rows, working the soil between the rows in both directions, but leaving about each tree a square of soil which receives no cultivation whatever. This shows quite plainly in figure 7. Upon this soil the brown rot-affected lemons drop and decay. With them are the leaves and rubbish, accumulation of sediment washed in by the winter rains, lemons decayed by other causes than brown rot,

and all the various refuse materials which accumulate in such a place. Moisture remains here near the surface late in the season and more or less all summer. The soil is never broken up or aërated, and, in short, presents ideal conditions for the development and propagation of the brown-rot fungus. Theoretically, to thoroughly break up the soil under the tree and keep it cultivated during the dry season, to mix up the old surface layer with fresh soil and let it dry out, and to clean out the accumulated débris and decayed matter of years should be a valuable means of keeping down the brown rot. Practically, the growers who have done this, thoroughly and persistently, have obtained excellent results. This does not mean that, in orchards where brown rot is abundant and the soil under the trees has been undisturbed for years, a single stirring of the ground will stop all the rot. Neither will cultivation under the trees during the wet season have much effect on the development of the trouble that season, as some have seemed to expect. The practice, to be successful, must consist in a thorough and rather frequent breaking up and stirring of the soil well under the trees, commencing in spring after the rains cease and continuing all through the summer. If this is accomplished the surface soil under the trees is pulverized and dried out to a considerable depth, access of air is permitted, and the fungus is killed. Instead of remaining active near the surface all summer, ready to start into more active growth and infect all the lower fruit on the tree with the first rains or even a heavy irrigation, the fungus in the infested soil is more and more dried out with each cultivation and subjected to the most unfavorable conditions for its development. By continuing the operation all summer and keeping the ground well stirred, brown rot the next winter can be checked, as shown by actual experience, to a very decided extent. We know of no case where the practice has been made of cultivating under the trees all through the summer, where the amount of brown rot as compared with neighboring orchards not so treated has not been very markedly reduced. In certain districts some of the very best and very worst orchards in respect to the rot are situated practically adjoining each other, and the only difference to which the absence of rot in the former can be ascribed is the fact that they are cultivated under the trees in summer while the others are not. (See experiment II-17, A and B.)

Methods of Cultivating Under the Trees.—These recommendations, we are aware, are somewhat ill-adapted to the style of pruning most commonly seen in many of our best lemon orchards, where the lower branches are allowed to spread down upon the ground with little attempt at cutting out. A large amount of fruit is produced on these low branches, where it can be easily and cheaply picked, and we would not be understood as unreservedly condemning this style of tree. The

grower must use some judgment in this respect. Our strongest point would be, however, that even with the tree very close to the ground it is possible to stir up the soil under the branches much more thoroughly and closer to the trunk than is commonly done. Even if the lower limbs are dragged and the lowest fruit scratched a little, it is better to carry out this most useful method of checking brown rot, rather than to lose all the lower fruit with the rot when winter comes, and allow the fungus to flourish unchecked in the soil to be carried into the house. With trees like those shown in figure 18, where the limbs just touch the ground without lying prostrate upon it, it is an easy matter to

FIG. 18. Low-pruned lemon tree, which can still be cultivated under.

cultivate sufficiently under the tree. This condition may be maintained by slight pruning at the bottom, with heavier cutting at first if the limbs are low.

One of the most efficient means of cultivating under the tree known to the writer is a spring-tooth harrow drawn by a considerable length of chain. After the ordinary cultivation of the orchard between the rows in both directions, a team is attached to this contrivance and the trees are "zig-zagged," the team going to the right of the first tree in the row, as close to it as possible, then swinging to the left and going on that side of the next tree, then to the right again, and so on down the row, coming back on the opposite sides. As the team passes around each tree the harrow, on its long chain, is pulled through under it, stirring and breaking up the ground in the corners left untouched in

the ordinary cultivation. This can be done with no serious damage with trees which look very low on the ground. There are also on the market several cultivators of more or less excellence, made for the special purpose of getting under the trees. In many cases growers have profitably had the ground under the trees broken up by hand, using mattocks or hoes, especially in cultivating for the first time ground which had long laid undisturbed, or for getting farther under than could be done with a team. As a general cultural proposition, without regard to brown rot, the breaking up and aëration of these dead, decay breeding, uncultivated areas is highly desirable.

For destroying the rot fungus, the more the ground under the trees can be stirred during the summer the better. The work should begin in spring, before the ground becomes hardened, and an effort be made all through the summer in connection with the usual cultivation to stir and work the ground under the trees and get it thoroughly dried out and stirred as deeply and as often as possible. The theory is very simple: Brown-rot fungus lives over summer entirely in the orchard soil. It is killed by dryness. Cultivation produces dryness.

Chemical Treatment of the Soil.—After discovering the soil habit of the fungus, and the fact that it is carried over the summer entirely in the ground under the trees, the idea presented itself that it might be feasible to kill the rot-producing organism in the soil by applying some fungicidal substance or liquid. The possibilities in this direction have been tried out quite thoroughly, but with no very promising results. While it is entirely feasible to kill the fungus in this manner, the amount of liquid required to saturate the soil to a depth sufficient to be of any value, or the amount of any dry substance necessary to cover the surface heavily enough to keep down the fungus, is so great that the expense and labor involved prohibit the use of methods of this sort. Figuring the depth and area of soil necessary to be treated, the cost of material which would be required in an orchard of any size, with the labor of applying it, would amount to more than the value of the fruit. The experiments along this line were made principally with copper sulphate, formalin, lime and sulphur.

Experiments with Copper Sulphate.—Using small boxes of soil in which brown rot-affected lemons had been mixed, it was found that good lemons laid on the surface soon became affected with the typical decay. When boxes of soil thus prepared were saturated with a strong solution of copper sulphate, the fungus and the power of infection appeared to be completely destroyed. Good lemons laid on such treated soil remained sound indefinitely, if not destroyed by other forms of decay. The solution used in these experiments contained 3% copper

sulphate and was applied in sufficient quantity to thoroughly saturate the soil. This strength is far above what could be used in a practical way in the orchard, both on account of the expense and the injurious effect on the soil. Experiments with the use of 1-10, 1-12, 1-100 and 1-200% copper sulphate showed little or no retardation of the rot. (See experiments I-30, I-65, I-66.) In experiments on orchard soil it was found that very large amounts of water were required to saturate even an inch or two of the surface. On rather dry ground 500 gallons per tree was not sufficient to give results of any promise in regard to thorough saturation. Furthermore, it was found that the neutralizing effect of the soil upon the sulphate solution was such as to make the minimum strength required to kill the fungus much greater than that found effective when the organism or its spores were in water. It is in fact practically impossible to sterilize the soil to any depth by this means, except by the use of enormous quantities of material. We have therefore given up all thought of the use of this method. (See experiment I-90.)

Experiments with Formalin.—The strength of this disinfectant is not neutralized by the soil to the extent that copper sulphate is thus affected. With small amounts of soil, as in boxes, it is possible to completely exterminate the brown-rot fungus, but in orchard practice this is out of the question.

Experiments with Lime.—It was found that a heavy covering of air-slaked lime has a decided influence in checking the rot fungus in affected soil. To have the desired effect, however, it is necessary to put on a solid covering an inch or more in depth all over the surface, and keep this undisturbed. No way has appeared of doing this economically and practically. The effect on the soil of the amounts of lime which would soon accumulate from the continued applications necessary is also an objection to this treatment.

Experiments with Sulphur.—A coating of sulphur on the soil has shown some effect in keeping down the fungus in box experiments, but nothing of value for actual practice.

From the results of these various experiments in soil treatment it will be seen that the only apparently practical method of checking the rot by such means lies in thorough summer cultivation of the ground under the trees. We lay particular stress on this matter because it represents a rational method of ordinary cultural practice and a desirable improvement in the present practice in many orchards, as well as a means of overcoming the brown rot to a very marked extent. In our mind it is the highest achievement in plant pathology to demonstrate

methods which in themselves represent improved practice from the cultural standpoint, whereby definite pathological difficulties may at the same time be overcome. The results attained where this method has been properly carried out have been so satisfactory that we have not thought it necessary or advisable to go further with investigations having in view the saturation of the soil with substances injurious to plant life, even though superficially the latter may show results of value.

THE PREVENTION OF INFECTION IN THE ORCHARD.

We have previously stated that brown rot may be controlled in the orchard either by eliminating the fungus from the soil or by protecting the fruit from infection, and have discussed the chemical and cultural means of attaining the former end. While it is true that the practice of cultivation under the trees in summer has succeeded in entirely eliminating the rot in a number of cases, and always shown most satisfactory results, yet in connection with this method, or where it has not been, or for any reason can not be carried out, it is very desirable to find every other possible way of preventing infection of the fruit. Even though the fungus be present in the soil, it is possible to largely reduce the infection which ordinarily takes place.

Pruning Up the Trees.

An effective, though not entirely practical means of controlling brown rot, is found in pruning up the trees so that none of the fruit hangs within two or three feet of the ground. (See Fig. 19.) We have experimented somewhat along this line and found that in the worst infected orchards trees pruned up to the latter height showed no more rot. This simply amounts, of course, to cutting off the lower fruit instead of leaving it to become infected. There is a practical benefit, however, in greatly lessening the amount of infected fruit which is carried into the washer and tents. It therefore will pay, to a moderate extent at least, to prune up the trees and get the fruit up off the ground. In low, heavy ground, where it is difficult to prevent surface flooding around the trees in irrigation and where the water from the rains settles and stands, we believe it will pay the grower to adopt a taller, higher style of tree and keep the fruit up at least two feet from the ground. This will save an immense amount of trouble from such places in wet weather.

Considerations of pruning and cultivation under the tree naturally go together. In cases of bad rot in the orchard we recommend radical treatment in both directions, trimming the trees up quite severely and stirring the ground under them in summer very thoroughly and fre-

FIG. 19. Lemon trees pruned high.

quently. The limbs may then be allowed to gradually come down again until the condition is reached which seems to be the most desirable under the circumstances. As said above, a large amount of cheaply handled fruit is produced near the ground; the grower must decide, according to the extent of his trouble with rot or his success in handling it by other means, what policy he shall adopt as to pruning.

The Use of Cover Crops as a Means of Preventing Orchard Infection.

One of the earliest orchard observations made in connection with this work was the fact that on trees under which the ground was covered with a green growth in winter there was much less rot than over bare ground. Carried further, and observed more carefully, it was found that on the same tree the fruit on a limb hanging over bare ground would rot badly, while that over a clump of weeds or other growth remained unaffected. When fully appreciated and looked for particularly, in lemon orchards in all the different sections, the importance of this discovery became evident. It was thought at first, theoretically, that weeds or cover crops under the trees in winter would favor the rot by holding moisture. Practically this is not the case, but just the opposite is true. Invariably where there is much growth on the ground the rot occurs on limbs hanging over bare ground, and only to a very limited extent over the covered ground. With a knowledge of the nature of the fungus, the fact thus established is readily

FIG. 20. Sound lemons hanging over cover-crop of vetch. The previous winter this same tree with the ground bare was badly affected.

explained. It is simply that the growth covers the ground and prevents the dust and dirt, with the spores of the fungus, from getting on the fruit. The experiment of tenting under the trees with burlap, shown in figure 17, was devised with the demonstration of this particular point in mind. By this means, as already described, infection was entirely checked, and the fact demonstrated that orchard infection takes place by spores coming from the ground under the tree.

It is not probable that any grower will see his way clear to cover the ground under his lemon trees with burlap or other similar material, though, if he could do this, it would be with the absolute assurance that all orchard infection with brown rot would be prevented, no matter how badly the soil was infested. The fact is a positive one, that any covering between the soil and the lower limbs of the tree prevents brown-rot infection to the extent that it actually covers the ground. The whole area of the orchard does not need to be covered, as infection apparently takes place only from the soil directly under a lemon by dirt spattering up with the rain, except in the case of large, thick trees, which retain a large amount of moisture.

After observing the effect of weeds on the ground in keeping down the rot, the most natural thought was of cover crops, another oppor-

tunity of making good cultural practice do double duty. If a chance growth of weeds would show such decided effects, it seemed reasonable that much more would be gained from a regular, sowed crop. With this in mind growers have been urged to sow cover crops in their lemon orchards, especially under the trees, and the results have been entirely in accord with the earlier observations. These crops have naturally been more or less successful, both as cover crops and as rot preventives, and the fact has been very plainly established that such a covering will prevent infection in proportion to the amount of growth which the crop makes under the trees during the season when the rot is active. A heavy, solid growth early in winter, under trees which had formerly lost all the bottom fruit, has almost entirely eliminated the trouble, lemons close to the ground remaining unaffected where over bare ground they would never reach half size. (See Fig. 20.)

As to the kind of crop to be used, the time of sowing, method of handling, etc., we would simply say that the only consideration so far as brown rot is concerned is to get a good heavy growth all over the ground, under the trees, early in winter. To accomplish this, the crop must be planted early, in September or October, and irrigated, if necessary, to produce a rapid growth. Under the trees the seed must be sown by hand, and may have to be raked in to some extent. As to the crop to be sown, there is some latitude of choice, and no one plant can be named as preëminently the best under all conditions. Of the leguminous plants in common use as cover crops the vetch, Canada pea, fenugreek and native bur-clover have been used in our experiments and observed in many orchards. The pea, used alone, is rather too coarse and spreading a plant to cover the ground as completely and quickly as is desirable, and does not grow as well in the shade as some of the other plants. It may be used mixed with other seed to thicken and support the growth. Fenugreek grows poorly in the shade and is easily set back by dryness, so that it does not seem desirable for this purpose. Bur-clover is somewhat capricious in its nature, requiring an early start and plenty of water to cover the ground as early in the season as is necessary to keep down brown rot. It grows well in the shade under the trees. Vetch has the same requirements, but does very well under the tree and when well grown makes an ideal ground covering. If started not later than October and given water enough (which must be done with any crop to get a thick growth), this may be regarded as the best plant for our purpose. In most of our lemon sections there is already sufficient information on hand to indicate what crop will best answer the requirements for that particular region. To cover the ground completely, well under the trees, and early in winter before the rainy, brown-rot season is too far advanced, is the only object which is of any value to this method.

FIG. 21. Ideal summer condition of lemon orchard for brown-rot control. Lower branches just touching the ground, and soil beneath well cultivated.

FIG. 22. Ideal winter condition of lemon orchard for brown-rot control. Heavy crop of vetch under the trees. Trees need not be pruned so high.

In brief, then, we recommend as one of our major conclusions in brown-rot control, the sowing of a cover crop in lemon orchards in the fall, planting the crop for this purpose especially under the trees. Naturally the crop will also be planted all over the ground for the ordinary purposes of a cover crop. The plant to be used must be one which makes a good winter growth and a thick, dense covering on the ground in as short a time as possible, particularly in the shade under the trees. Vetch and bur-clover seem to be among the best plants for this purpose, especially the former. For good results the crop should be planted in September or early October, sowing by hand under the trees, and the ground then furrowed out so that it can subsequently be irrigated. If fall rains are lacking, the ground should be irrigated and the cover crop pushed along as fast as possible. If this is done, a good ground covering can be obtained by the time that the rot begins to be abundant in January. If possible, the crop should be left on the ground until the rainy season is nearly over. After plowing-in the crop summer cultivation should begin as already described. Figures 21 and 22 show the ideal summer and winter condition of a lemon orchard for controlling brown rot.

We have considered only the leguminous crops, owing to their value as soil enrichers, as well as the benefit to be derived from them in suppressing brown rot. There are cases, however, where a sowing of barley or any quick-growing, vigorous crop is of great value in controlling brown rot in the orchard. The worst cases of rot are usually in places where there is a wash through the orchard, the ground being kept bare and moist by surface water running down from farther up the slope. There are also cases where, for one reason or another, it is impossible to get a leguminous cover crop started and properly grown in time to keep down the rot. In such cases a sowing of barley will often be most useful. By this means a quick growth is obtained, which prevents the water washing over the surface to quite an extent, keeps the ground covered under the trees, and aids very materially in preventing infection by brown rot. In badly affected orchards the first aim of the grower should be to prevent any washing of water over the surface, and to get a green covering of some kind on the ground, especially under the trees, before the heavy rains come on. The bare slopes, where the water of every storm washes over the surface unrestricted, and the low, wet ground where water accumulates and stands, are the principal breeding places of brown rot in the orchard.

The Use of Artificial Coverings on the Ground for Preventing Brown Rot Infection.

The decided success obtained by covering the ground with green crops, and by the burlap method, suggested the possibility of spread-

ing some other substance under the trees to protect the fruit from infection. It is undoubtedly true that a layer of any substance which would cover the ground thoroughly would answer the purpose and keep down rot effectively, the only question being that of economy. The only substance which has suggested itself as being at all cheap and abundant enough for this purpose is straw. This in some cases can be obtained cheaply enough to make feasible a heavy covering under each tree in the orchard. Figure 23 shows an experiment of this nature. Four trees were chosen where rot had been abundant, and all affected fruit removed, as with the burlap trees. The ground under

FIG. 23. Control of brown rot by covering ground under tree with straw.

each tree was thoroughly covered with straw, using about a bale to the tree. During the remainder of the winter only two lemons became affected with brown rot on the straw-protected trees, and these were on limbs which hung out over bare ground. The record of the 30 unprotected check trees is given on page 28, in connection with the burlap experiment, showing from 4 to 53 brown-rot lemons per tree, with an average of over 20. There is no question that this is a most effective measure, and in bad cases of orchard infection, where the straw can be obtained at any practical figure, we strongly recommend its use in the winter season, both in connection with summer cultivation, and, if possible, with the cover-crop method. The amount of straw

available is the only limitation. If the ground can be solidly covered, brown-rot infection can be absolutely prevented.

There are possibly other substances which will suggest themselves for this purpose, which can be obtained in individual cases. Anything which will cover the ground in the manner described, without injurious effects of any sort to the tree or soil, will prove effective.

THE CONTROL OF BROWN ROT IN THE PACKING HOUSE.

The more striking results of this work have been obtained in the treatment of lemons for the prevention of brown rot in the packing house, regardless of conditions in the orchard. This is the case, however, simply because with the picked fruit we can estimate in dollars or boxes of lemons the actual losses and savings, while in the orchard results are of a more general nature. If, therefore, in the succeeding paragraphs on the handling of the fruit in the house, we seem to show more definite results than in the discussion of methods for the orchard, we would state emphatically that this is not the case, but that the methods of orchard treatment described have been worked out and tested with the same degree of accuracy and completeness as those for the packing house, and are fully as valuable and important. It would be most desirable could we overcome the trouble entirely in the orchard by eliminating the source or possibility of infection, and this is feasible to a very large extent by the simple cultural means described. Under actual conditions, however, especially in the associations where fruit from many different orchards comes to the house, this can be only partially accomplished, and in every case we must apply every possible means to bring about as complete a control of the rot as possible.

In discussing the nature of the brown rot and the manner in which lemons become infected, we have stated that there are three sources of infection: In the orchard, in the washer, and by contact. The last two come under the consideration of control in the packing house.

Prevention of Washer Infection.

We have shown that the washing machine, in which the fruit is submerged in a tank of water, is by far the most prolific source of infection with brown rot. The water becomes infected, not by the few affected lemons which go through, but by the dust and dirt from the orchard brought in with the boxes and fruit, in which the spores of the fungus are abundant. In this manner the wash water becomes filled with spores, and infects with brown rot a large amount of previously sound fruit. This source and manner of infection was the first discovered in the investigation, and much attention has been paid to its exact

nature and means of prevention. In attacking a problem of this sort the most natural method was along the line of disinfecting the wash water with some substance which would destroy the fungus without injuring the fruit, and this has been the nature of our work in this direction. The first experiments showed that infection could be very easily prevented in this manner, the chief points to determine being what substance to use, and in what strength. One of the most important

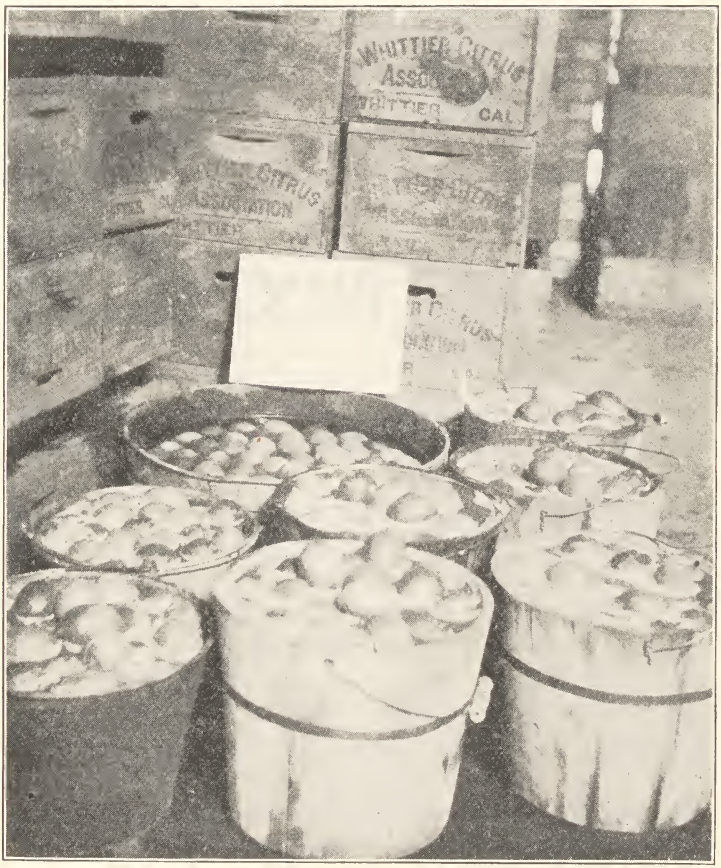

FIG. 24. Bucket-soaking method of disinfection experiments.

considerations was that of economy, since the ordinary washer holds 1,000 gallons, and with the losses and additions during a day's run much more than that quantity is used. The determination of the best substances and strengths to be used for the purpose of wash-water disinfection has occupied a large share of our attention, and has been carried to a very satisfactory conclusion. A very large number of experiments have been carried out under all sorts of conditions, and

with many different objects in mind, in order that these points might be thoroughly worked out.

Of the disinfectants in common use, copper sulphate (bluestone), formalin and potassium permanganate have received our principal attention, seeming to suit the purpose best. The following method of experiment was adopted: Four-gallon buckets were filled with water, and the water infected with the brown-rot fungus. Infection was accomplished in the earlier experiments by soaking several affected lemons in the water over night, and rubbing off all the fungous growth from the surface into the water next morning. Water is made very highly infectious in this manner. In the later work, after the infectious nature of orchard soil was discovered, the buckets of water for the experiments were infected by placing in each about a pint of soil from ground known to contain the fungus. This could be taken almost anywhere in an orchard during the winter, but as the dry season advanced it was necessary to get soil from beneath the trees, and from August to the beginning of the rainy season soil from any source gave very uncertain infection. After infecting a sufficient number of buckets for the experiment in hand in this manner, the water was poured back and forth from one to the other until thorough mixing had been accomplished, in order that the infection might be uniform. Any disinfectant to be tested was then added to the buckets in the desired strength, and a certain number of good lemons placed in each bucket. (Fig. 24.) Check buckets were left in each case without any disinfectant, in order to show that the water was properly infected. Ordinarily in every experiment the checks would not only show 100% of brown rot, all the lemons becoming affected, but every lemon would be infected in a great many different places. (Fig. 10.) The good lemons were soaked long enough to insure infection, 2 to 24 hours, or usually over night; then taken out of the water, placed in boxes, and put away in a tent for the rot to develop, being examined frequently, and held for at least a month for all the decay to show itself. Many experiments were also made in the machine itself, and in many other ways, of which those of most importance will be alluded to. The time of soaking in the buckets is very excessive compared to the fifteen or possibly thirty minutes which lemons remain in the washer during the ordinary washing, but the idea was to make the test a severe and thorough one. Besides the disinfectants mentioned, experiments were made with boric acid, salicylic acid, sodium benzoate and sulphide of potash, but none of these substances appeared to be worthy of much consideration for our purpose.

Experiments with Formalin.—This substance is a colorless liquid, and has well-known disinfectant powers. It was tested by adding

definite amounts to the buckets of infected water, and then soaking good lemons, while certain buckets containing good lemons in infected water, without any formalin, were held as checks. It was found that when used above a certain limit of strength lemons were very badly injured by this substance. If the solution was too strong the rind became pitted, spotted, and the fruit completely spoiled. This depended on the time of soaking as well as the strength of the solution, a weaker strength causing injury by long soaking. Below a certain strength, however, the fruit can be soaked in the solution indefinitely without burning.

One of the striking results of these soaking experiments with formalin was the large amount of blue-mould (*Penicillium*) rot which always occurred on fruit injured by the solution. The condition was the same as that produced by bruising; lemons injured by too strong a treatment almost invariably became affected by this form of decay. The most interesting point was the fact that visible spotting or burning of the lemon was not necessary to produce this susceptibility to *Penicillium*. With strengths of formalin, or periods of soaking just under that necessary to produce visible injury, a large part of the treated fruit would go down with blue mould, while that given less severe treatment retained its normal resistance. The natural explanation of this occurrence is that treatment just below the limit of visible injury had still so weakened or killed the outer rind of the lemon that its resistance to the attacks of the mildly parasitic fungus had been largely destroyed. (See experiments I-48, I-61, II-4.) It is noteworthy, however, that in the experiments with copper sulphate, and other disinfectants, so far as they were tested, this result did not appear.

The strength of formalin solution in which lemons can be safely washed, without danger of injury, can be stated at about 1-20%. (One part to 2,000, or one pint to 250 gallons of water.) 1-10% shows no bad effect in one hour's soaking, but produced both a slight burning and excessive blue mould in longer treatments, so we can not recommend the solution for use as strong as this.

For controlling brown-rot infection less strengths than this have been effective. In every case in the bucket experiments strengths down to 1-100% (1 part to 10,000, or 1 pint to 1,250 gals.) have completely checked infection, while 1-200% has shown almost as good results, with practically no rot except a doubtful case in one experiment. These results were obtained from many different experiments and repetitions, and checked in every case with tests of the same water with no disinfectant, resulting under the latter conditions in 100% of infection of the nature shown in figure 10. In the washer itself, infected with a bucketful of orchard soil in the water, which is an extreme test, a strength of 1-50% (1 pint to 625 gallons) has seemed necessary for

complete disinfection in every case. We would, therefore, not recommend the use of less than this strength in practical operations.

Formalin has not come into general use to any extent for washer disinfection. It is somewhat more expensive than other substances which give good results, and not as powerful in effect, requiring greater strengths to accomplish the same result. There is also some prejudice against its use on the part of most lemon men, on account of the injury to the fruit which results from the use of too strong a solution. This injury can be entirely avoided by using a proper strength, under which conditions burning of the fruit or susceptibility to blue mould is not, so far as we know, produced by formalin in the slightest degree. It has the advantage of being a clear solution, with no danger of staining the fruit, and has no corrosive action on the metal of the tank. The matter of expense is an objection to its use, though this is by no means prohibitive. It costs four or five times as much as bluestone and must be used about 50% stronger, making the total expense, with a full-sized tank running continuously, about 75 cents per day. With the 1,000-gallon tank, one and one-half pints of formalin should be poured into the water in the morning, and mixed well with it. If running all day, put in another pint after noon, in the same water.

Experiments with Permanganate of Potash.—This substance has been found to give considerable satisfaction for the purposes under discussion, and has been used thus far in the lemon houses more generally than any other disinfectant. It is a crystalline substance of a dark purplish color, readily soluble in water, to which it gives a very intense color. A very small amount of the permanganate will color deeply a large amount of water. The danger in the use of too strong a solution on lemons lies in the possibility of staining the fruit, rather than that of burning or otherwise injuring it.

Permanganate is mild in effect compared with formalin or bluestone. It does not corrode iron. The staining effect is seen especially on rough, scarred fruit, on which the scars take up the stain very readily, and are made prominent. 1-50% (1 pound to 625 gallons) is about as strong as this substance can be used in the washer, without some slight discoloration of the scars and butts of the lemons. Even 1-200% causes slight staining with long soaking, but the strength first mentioned is safe in ordinary washing. In bucket-soaking experiments 1-200% (1 pound to 2,500 gallons) has almost always produced complete disinfection. This strength is close to the minimum, however. In experiments with the washer, with a large volume of badly infected water and a good deal of fruit, a strength nearly up to 1-50% has seemed necessary to insure complete disinfection, although less

strengths were usually effective. (See Figs. 25 and 26.) Early in our work we recommended permanganate of potash for washer treatment above any other substance, and it has been most generally used. The strength used has averaged from about 1 pound to 1,000 gallons (1-80%) to 8 ounces to 1,000 gallons (1-160%), putting in three quarters of this quantity in the morning and the balance in the afternoon. In most cases this has given good satisfaction, and all infection in the washer has been completely checked. There have been instances, however, with fruit coming from very badly infected orchards on heavy soil, where even the greater strength given above has not produced complete disinfection, as proven by actual tests of the wash water. (See experiment II-16.) This fact has tended to weaken our confidence in the permanganate treatment somewhat, inasmuch as the use of more than one pound to 1,000 gallons is objectionable on account of the deep color produced. On account of the uncertainty of effect we no longer urge the use of permanganate, though several houses are still using it with perfect satisfaction.

The method of using the permanganate is to weigh out the requisite amount, dissolve it in a bucket of water, and pour into the tank. We would advise those using it to use a pound in the morning, and 8 ounces more in the afternoon to 1,000 gallons. The substance should be carefully weighed out, and no guesswork indulged in, as the estimation of the strength of the permanganate solution by its color, a method in which some have come to think themselves infallible, is far from an accurate one. The cost of the material is about 20 cents to 30 cents per pound.

Experiments with Copper Sulphate.—The disinfectant properties of copper sulphate, or bluestone, are too well known to need explanation, and this material has been used quite extensively in our work. It has proven the best available substance for the present purpose. While having some faults, it is cheap, effective, and can be used in the greatest strength necessary without the slightest injurious effect upon the fruit. It is the most powerful of the disinfectants experimented with, producing disinfection at a less strength than any of the other substances. At the same time it is considerably cheaper, costing normally about 6 cents a pound, though recently it has been up to 9 cents and 12 cents. The effect of too strong a solution of bluestone upon lemons is to burn and pit the fruit very badly. Its effect is extremely bad in this way when not sufficiently diluted. 1-20% (1 pound to 250 gallons) produces no apparent injury in several hours' soaking, though we would hardly recommend the use of this strength. 1-50% is entirely safe.

The use of bluestone for washer disinfection is complicated by a factor not met with in the use of the other substances discussed. This is the strong affinity of the material to combine with alkaline substances in the wash water, and with the iron of the tank; this is an important consideration. With the minute quantities of copper sulphate employed, an amount which would produce complete disinfection in distilled or fairly soft water in a wooden bucket might be entirely precipitated and neutralized by the alkali in a harder water, or by the metal of an iron tank. We can not therefore draw the figure too fine for the minimum strength necessary to disinfect, but must allow for any condition which is likely to occur. So far as disinfection is concerned this is not a serious problem, as the material is cheap, and we can use without danger a strength sufficient to hold its own in any water likely to be used. A more serious matter, and the only real objection to the use of bluestone, is the injurious effect upon the tank. This has deterred some houses from the use of this material. Still, it is possible to prevent this quite largely by keeping the inside of the tank covered with asphalt paint, and the use of bluestone is otherwise so satisfactory that this objection has not seemed a very serious one in most of the lemon houses. Indeed, it would be much cheaper to buy a new tank at very frequent intervals than to take a chance of allowing the rot to spread in the washer. The injury, however, is not a severe one, and by painting the inside of the tank, as just mentioned, its life is very little, if any, short of the normal. In machines with a wooden tank this difficulty does not occur.

In distilled or fairly soft water an extremely dilute solution of copper sulphate is sufficient to kill the *Pythiacystis* fungus and prevent infection. Strengths of 1-500% (1 part to 50,000, or 1 pound to 6,250 gallons) have almost always given complete disinfection in ordinary water, with the checks showing 100% rot, while 1-1,000, 1-2,500, and even 1-5,000% (1 part to 500,000, or 1 pound to 62,500 gallons), have often checked infection completely and always very much reduced it. With distilled water in a wooden vessel, infected with a pure culture of the fungus, our experience gives reason to believe that one part of bluestone in one million of water would show decided disinfection. In practice, with a more or less alkaline water, metal tank and washer parts, and much soil and other matter in the water, it is not safe or desirable to attempt the use of any such weak strengths as these, especially when 15 cents' worth of bluestone per day will afford complete protection from any possibility of infection in the washer. We have already stated that a strength of 1-50% (1 pound to 625 gallons) is perfectly safe to use, so far as any damage to the fruit is concerned, and some houses are using the solution as strong as this as a regular practice.

FIG. 25. Result of infection of washer with orchard soil. Brown-rot lemons at the left. From Bul. 184, Cal. Agr. Expt. Sta.

FIG. 26. Lemons washed in same water as those in Fig. 25, after disinfection of water. From Bul. 184, Cal. Agr. Expt. Sta.

At present we recommend copper sulphate as the best substance for use in disinfecting the tank against infection with brown rot. Its only fault is the corrosive action on iron, but if the inside of the tank is kept well painted this is not a very serious one. It is absolutely effective at a strength well below that which causes injury to the fruit, and is cheap, colorless, and with no undesirable effect of any kind except the one mentioned. As the proper strength for general use we would recommend, to 1,000 gallons of water, about 16 ounces of bluestone in the morning, with 8 ounces more added in the afternoon. The material dissolves rather slowly in cold water, so it is best to keep a stock solution on hand in a barrel. This solution may be made in the strength of two pounds to the gallon. To take out one pound of bluestone it is then necessary to dip out one-half gallon of the stock solution. For 8 ounces of bluestone, take one quart, and in the same proportion for other amounts. It is very essential to keep the stock solution at the proper strength, and figure correctly how much to use. In the whole operation of washer disinfection and washing with these chemical solutions, the operator should know accurately at all times, in pounds and gallons, just what he has in the tank. The system of judging the strength of the solution by the color of the water, or any other guesswork method, should not be tolerated if satisfactory results are to be obtained.

Fumigating the Washer.

One of the first methods resorted to by lemon men in attempting to control the brown rot was the fumigation of the washer at frequent intervals with burning sulphur, formalin gas or hydrocyanic acid gas. The empty tank was covered with a canvas, and the gas produced inside. This method, when the water was not being disinfected, has at times shown decided results in checking rot infection. Particularly with sulphur, when the machine was treated with very strong fumes at times of abundant rot, a marked diminution in the amount of infection often resulted following the treatment. Usually the amount of rot decreased immediately after the sulphuring, but began at once to increase again. Occasionally a treatment of this sort in early summer, just at the end of the normal brown-rot season, has shown decided results in bringing the prevalence of the trouble to an end. These effects are due probably to the killing of the fungus growing in the machine itself. So long as the spores are being continually introduced with every box of fruit, this effect is very short-lived and of no practical value, but when the fungus is becoming less abundant and nearly lifeless in the soil at the end of its season, fumigation of the washer shows its best results. In any event this treatment is quite needless, if the water is kept thoroughly disinfected.

General Considerations Regarding Washer Disinfection.

By thorough disinfection of the wash water brown rot can in most cases be almost entirely eliminated from the fruit in the house. So effective has this treatment been, that in a single season the brown rot has been completely overcome in many houses which formerly were in a deplorable condition and losing thousands of dollars each year from this cause. By the expenditure of a few cents per day for bluestone in the wash water the trouble has been checked at its very source. With improved conditions in the orchards, the success with which the problem is being met will be even greater. In cases where washer disinfection does not reduce brown rot in the house to a minimum, the manager may be sure that one of two things is the trouble: he either is not disinfecting the water completely, or a large amount of rot is coming in from the orchard in such an undeveloped condition that it is not apparent. The former condition may be easily detected. This is most readily done by laying aside in a moist place some of the lemons which are found sunk to the bottom of the tank at night. There is always a considerable number which do this during the day, and these, if any, will contract the rot if there is any infection from the water. If these bottom lemons, after keeping them a week or two, show an abundance of brown rot, it may be taken as sure proof that the water is not being disinfected. We feel sure that such a case has not occurred, and will not occur, under the use of bluestone in the strength recommended. It has occurred with permanganate, at a strength beyond which it is not desirable to go on account of the color, and may occur with any disinfectant if used too weak. In such cases we strongly advise the use of bluestone at a strength of 24 ounces to 1,000 gallons, divided into morning and afternoon portions of 16 and 8, as described above. If there is an objection to this for any reason, we suggest formalin as next best, practically a sure disinfectant, but more expensive than bluestone. Two and a half pints per day in 1,000 gallons, used as directed in the paragraph on the subject, should give good results. Permanganate seems to be more uncertain in effect than either of the others, and can not be increased sufficiently in strength to insure absolute disinfection in refractory cases without producing an objectionable color.

One of the results of incomplete disinfection is usually a retarding of the development of the rot, so that, where otherwise it would show plainly in the fruit within a week, it straggles along for two or three. This has been a very marked feature of our experiments when a strength of the disinfectant was reached which only partially disinfected, and the same thing has appeared in packing houses where the disinfection of the washer was found to be incomplete. (See experiments I-84, I-88.) This is worse than no disinfection at all, since the

subsequent handling of the rot is more difficult on account of this delayed development. It is, therefore, an excellent plan to keep a check on the disinfection by saving out occasionally the bottom lemons at night. They should not develop brown rot any more than the others, if the water is being properly treated. Another good test is to leave the water in the tank over night after the day's run, and let a number of good lemons soak in it. If these develop infection after keeping a week or two, the water is not thoroughly disinfected.

In general, it is evident that the amount or strength of any disinfectant necessary to keep the water perfectly free from danger varies considerably at different times, according to the season, temperature, and character of the water, amount of sediment, abundance of the fungus in the orchard from which the fruit comes, and other considerations. It is, therefore, best to use the disinfectant at the maximum strength for safety to the fruit, rather than at the minimum of possible disinfection. We strongly urge the use of the strongest solutions recommended, even though in most cases a considerably weaker solution would be effective. The material is too cheap to take any chances in a matter of such great importance. The effect on the tank is also of no consequence compared with the saving of the fruit. Again, we would urge the greatest care in measuring and weighing out the materials carefully and accurately at all times, not depending on guesswork for anything.

In case the water is being thoroughly disinfected, and still a large amount of brown rot develops in the tents, the conclusion may be reached that this is orchard-infected fruit in which the rot had not advanced far enough to show itself. This may occur abundantly at times from certain orchards, but only for a limited season, such as after rains. No treatment in the house can check rot of this kind, as when a lemon is once infected nothing can prevent its decay. (See experiments I-53 and I-83.) Good orchard treatment must be the solution of this problem. If the ground under the trees is well covered in winter, and cultivated in summer, there will be little of this sort of infection. All that can be done in the house is to watch the fruit carefully as it goes through the washer, in order to cull out all that show the slightest sign of rot.

Picking Bottom Fruit Separately.

An excellent practice in orchards where there is known to be a large amount of affected fruit on the trees is to pick the tops and bottoms separately. Most of the infection is in the lower fruit, and by keeping this by itself in picking, washing and curing, we avoid mixing it with the little-affected top fruit and save much handling and

contact infection in the tents. The disinfection of the wash water should be made especially thorough at times when infection is active and much affected fruit in evidence, in order that no further infection may take place in the washer.

HANDLING OF AFFECTED FRUIT IN THE HOUSE.

In spite of all precautions, a certain amount of brown rot may occur in the tents on account of the amount of the fungus existing at present in our orchards, and there are also cases where the methods of rot prevention described have not yet been put into practice as fully and thoroughly as might be. It will, therefore, be of value to describe the most successful methods in use for handling the rot in the house, in case one has to make the most of circumstances. These methods were mostly in use before this investigation began, and represent a high degree of intelligence and adaptability to circumstances on the part of those who developed them.

The important factor in the whole consideration of the handling of brown rot, after it has started in the house, is contact infection. No matter how much rot may show in the tent, the fact is positive that it all started either in the orchard, the washer, or by contact. There is no possible means of spread in the tent except by the last method. The extreme virulence of the fungus, however, and the rapidity with which it may spread by simple growth from fruit to fruit in the box, makes its control when well started almost a hopeless matter, unless the proper methods are very carefully applied. Carloads, and even whole months' pickings of lemons, have been lost by some houses starting with unchecked washer infection, and carried along by handling of the affected fruit, which increased rather than checked the contact infection.

The key to the situation lies in the segregation and separate handling of what have come to be called "contacts"; these are lemons which show no signs of decay, but which have been lying in contact with affected lemons in the box. In the first experience with brown rot, the lemons in the curing boxes were simply sorted over when the rot began to show badly, the affected ones thrown out, and the apparently good ones put back in the tent or packed and shipped. This led to an enormous and inexplicable amount of further decay. Although all the affected fruit seemed to have been taken out, the rot would develop even more abundantly than before, the fruit would be again sorted, and again the rot would develop, until the process became one of simply handling over the fruit time after time until it had practically all rotted. Several hundred boxes of apparently sound lemons would gradually dwindle to four or five before the decay finally stopped

This was the worst feature of the whole situation, and when the cause and manner of infection and spread of the rot were entirely unknown it is not surprising that extreme discouragement was felt in the lemon business. From all appearances, new infection was continually taking place in the tent, and the prospect of finding any means of preventing this seemed very poor indeed. It seemed like a decay similar to blue mould, of a very much more virulent nature, as though the spores or germs of some infectious organism were present in extreme abundance, like those of *Penicilium*, causing continual infection of the stored fruit.

In the less systematically conducted houses the only relief for this situation seemed to be to pick out the rotten fruit as soon as curing could be effected and hurry the remainder to market, taking a chance that it might not rot too badly in transit, but might reach the retailer or consumer in time to return some kind of a profit. The effect of this system on the market and on the reputation of California lemons may be imagined. In the better class of houses the situation was studied very closely and considerable relief found. It was found that the source of the continual spread of the trouble in the house was contact infection, and that fruit which did not develop brown rot soon after being put in the tent remained free from the trouble ever after, *unless it had been lying in contact with an affected lemon.* By carefully sorting out these "contacts" at the first picking over, it was found that practically all the subsequent rot developed in them, and little or none in the lemons which had not been in contact with affected ones. In other words, it was found necessary, in order to clean the fruit of brown rot, to take out all lemons which had been touching affected ones, as well as the latter themselves, the continued spread of the rot having come from the former class of fruit. By doing this once, or possibly twice, to get a few belated cases or overlooked "contacts," the brown rot could be eliminated from the body of the fruit. The process was then repeated with the "contacts" themselves, the affected ones being picked out after a sufficient time of storage, and the "contacts" from them again segregated. In this way a considerable quantity of fruit would be released from quarantine, and restored to the condition of the good fruit from the original picking over. Thus, by close and careful sorting, much fruit could be saved, and the spread of the rot confined to a comparatively small amount. The system, however, was a very laborious and expensive one. Since, when the rot was abundant it might develop in nearly every box of fruit with several separate originals in each box, if sorted too quickly the originals would not have all developed, and if left too long much spread by contact would occur, and the expense of sorting became excessive. Moreover, the condition of the good fruit was injured by so much handling, the amount of fruit

actually lost was very large in spite of the most careful attention, and the house became filled with the various classes of fruit made in the different sortings. This much was accomplished, however, and is worthy of record: that certain houses, although troubled with brown rot as badly as any, kept the rot out of their shipments and sent to market fruit as sound and of as good keeping quality as it would have been if brown rot had never been heard of. Under the peculiarly difficult and trying circumstances this is very much to their credit.

Thorough disinfection of the washer, and proper orchard practice, have eliminated most of this, but a description of the best methods of handling will be of value. When brown rot is occurring in the fruit, it should be watched very carefully in the tent in order not to allow contact infection to spread too far. The first sorting should take place after a long enough period has elapsed to allow the original rot to develop, but not long enough to allow it to spread any more than can be avoided. The time varies with the season, temperature and other conditions, but is usually from ten to thirty days, more often nearer the former figure. This can only be determined by watching the fruit. An experienced man can tell by the odor, and the gathering of flies on the boxes, when the rot is getting well developed. When the time for sorting comes, the boxes are taken down and the fruit carefully handled over into new ones. All lemons which are neither affected nor touching affected ones are simply laid over into the other box. Blue moulds are thrown out and the lemons in contact with them put with the good, as there is no danger from them. When a brown rot is found, the sorter should proceed with extreme care. All the sound lemons which have the least suspicion of having been in contact with one that is affected, should be put into a separate box as "contacts." The affected ones are to be thrown into a refuse box, and hauled away to a place not in any citrus orchard and with no drainage into one. If a lemon shows the slightest infection, even the minutest spot, it should be thrown out, as it will invariably go down. The "contacts," it should be understood, are lemons which do not show any sign of decay, but which have simply been touching affected ones. If the sorting could be done by an expert, he could no doubt put many of these in with the good with safety, since no infection takes place except on the lemon lying in contact with the affected portion of another and the fungus actually growing across, but with average labor it is much safer to have every lemon which touches at all put with the "contacts." The chief precaution necessary is to prevent the "contacts" from rolling away from the affected lemons by careless handling. A heedless worker has the tendency to handle over the fruit from box to box mechanically, and, before he notices a case of brown rot, will take away the lemons around

it and let the "contacts" roll down and mix with the good fruit. It is, therefore, advisable to leave this work to a few selected men. The best system is to let the general help take down the boxes and transfer the fruit until they find a box with brown rot; as soon as this is discovered, the box should be set aside and left for special men to handle.

With fruit which contains a large amount of rot it is sometimes advisable to handle it in trays instead of boxes. In this way the fruit is in one layer and contact can take place only in one direction. The lemons are also less closely pressed together than in a box, and the amount of contact is reduced for this reason. The chief objections to the system are the large number of trays required to handle the fruit, and the difficulty of handling the trays without allowing the lemons to roll about and thereby losing track of the "contacts." If the trays can be provided and handled carefully, their use will undoubtedly reduce the amount of contact infection. Some handle all the fruit directly from the washer in trays when rot is abundant, or again only the lemons from badly affected orchards, or from the bottoms of the trees, are cured in this way. If the fruit is reasonably free from rot, there is no advantage to be gained from the use of trays. The practice is quite common of putting the "contacts" onto trays, and holding them in that manner for the rot to develop. By some they are wrapped in paper, as for shipping, and put back into boxes, and this prevents further spread by contact quite completely.

The whole operation of handling a large amount of brown rot in the house, checking its spread, and eliminating it from the fruit is laborious and expensive in the extreme. It is only with the greatest care that it can be done at all successfully. The system is very simple, however, and depends entirely upon the thoroughness with which the contact lemons are taken out of the body of the fruit along with the actual rots. The subsequent proceedings lie chiefly in working the "contacts" again by the same method in order to save as many of them as possible. With proper treatment in the orchard, and thorough disinfection of the washer, there will be no necessity of any considerable amount of this work, and in these directions lies the only rational and at all successful means of brown-rot control.

OTHER FORMS OF CITRUS DECAY.

The common form of rot in all citrus fruit is that caused by *Penicillium*, commonly referred to as blue mould. This fungus is omnipresent in the packing houses, and rapidly takes possession of all bruised or weak fruit. It is not an active parasite and gives very little trouble with sound fruit in good condition. An intimate acquaintance with citrus decay soon leads to the suspicion that there are two different

species of *Penicillium* present, one a blue green and the other an olive-colored mould, with differences in growth as well as color. We have substantiated the fact, by means of pure cultures and inoculations, that there are two distinct species. The nomenclature of these forms is so uncertain that it is hardly worth while to discuss names, but we distinguish the two species as *P. glaucum* Link. for the blue green, and *P. digitatum* Fr. for the olive green. The characteristic growth of the two on lemons is shown as well as can be done in a photograph in figure 27. *P. glaucum,* on the left, has a bright bluish color, and grows characteristically, with a small amount of surface mould in the center of a softened, rotten area. The amount of surface mould which it forms is very much less than in the other species (the two lemons in the picture having been inoculated at the same time), and the blue-green

FIG. 27. Forms of blue-mould rot. At left *Penicillium glaucum,* at right *P. digitatum.*

spore mass develops almost as fast as the surface mycelium, which is at first white. The characteristic growth of *glaucum* on a lemon, therefore, consists of a small amount of bluish mould in the center of infection, a very narrow edge of white about this, and an outer, wider band of softened but not mouldy lemon tissue.

P. digitatum, the olive species, grows rapidly over the surface, first as a white mould, which later turns olive from the center rather slowly. The lemon is not softened outside the mouldy area, and the mould develops over the surface much more rapidly than in the other.

Glaucum is more actively parasitic than the second species, causing some infection by contact. *Digitatum* is the more common, and forms the predominant type of blue-mould decay. It is apparently the same form as that described by the writer some years ago as being found commonly on oranges in market in the East.*

*See Botanical Gazette, Vol. XXIV, No. 2, Aug. 1897, pages 103 and 104.

Another not uncommon rot is that shown in figure 28. This has been given the name of "cottony fungus," and sometimes causes considerable losses. The characteristic of this form of decay is a dense, white-mould growth, which spreads very rapidly over the fruit in the boxes. The resulting rot is decidedly virulent, large masses of sound, green fruit being involved. If the trouble was more common, it would be

FIG 28. Cottony-mould rot (*Sclerotinia*).

a very serious matter indeed. Practically, however, it is not often abundant enough to cause much concern. The fungus is a species of *Sclerotinia*. In the white, cottony-mould growth solid black bodies develop, as seen in the illustration. These are sclerotia, a stage in the development of the fungus. If allowed to lie for a time on moist soil, they throw up little stalks and produce funnel-shaped, toadstool-like bodies, which contain the spores of the fungus. (Fig. 29.)

FIG. 29. Spore-bearing stage of the cottony-mould fungus. (*Peziza* form of *Sclerotinia*.) Natural size.

ILLUSTRATIVE EXPERIMENTS.

These illustrations are chosen from the large number of experiments carried out during the progress of the work, as showing typically the results, and the methods of arriving at the facts upon which the conclusions given in this bulletin are based. All the results given were supported by many other experiments of a similar nature and a variety of tests along the same lines. It has seemed to the writer that a more readable publication will result from thus grouping the specific data of most of the experiments in an appendix form, with references in the text from time to time to the experiments upon which conclusions are based, rather than to encumber the main portion of the bulletin with the detailed methods and results of the various experiments.

Soaking Good Lemons in Water in Which Affected Ones Have Been Soaked Produces Infection.

Experiment I-19; July, 1905. Soaked several lemons having brown rot in bucket of water for two hours. Removed, and put in 15 good ones; 9 of the latter became affected with brown rot.

Did the same with *Penicillium* rot. No infection resulted.

Experiment I-31; August, 1905. A. Soaked one lemon affected with brown rot in bucket of water for twenty hours. Then soaked 50 good lemons in same water for ten hours. 17 developed brown rot.

B. Soaked 20 affected lemons instead of one. Otherwise as A. Good lemons all took brown rot.

Experiment I-51; August, 1905. Infected six buckets of water by soaking affected lemons. In A soaked 50 good lemons fifteen minutes; 1 brown rot resulted. B. Soaked good lemons one-half hour; 1 brown

rot. C. Soaked good lemons one hour; 13 brown rots. D. Soaked good lemons two hours; 30 brown rots. E. Soaked good lemons four hours; 33 brown rots. F. Soaked good lemons eight hours; 50 (all) brown rots.

See also checks in many other experiments.

Boiling Infected Water Prevents Infection.

Experiment I-24; July, 1905. Soaked a box of lemons affected with brown rot in a tub of water over night. In the morning, boiled half the water for ten minutes. Then placed 100 good lemons in each portion, boiled and unboiled, and soaked over another night. In the unboiled, 79 became affected with brown rot; in the boiled, no rot resulted.

Affected Lemons Placed on Soil Make It Infectious.

Experiment I-33; August, 1905. Dug up and watered a plot of ground in a garden away from any citrus trees. On one half the plot laid brown rot-affected lemons all over the surface; none on the other half. Kept both plots wet for twelve days; then removed the rotten lemons and placed 80 good ones on the surface of each. On the infected soil all but two of the good lemons took brown rot; on the uninfected soil no brown rot resulted.

See also experiments on soil treatment. (I-30, I-65, I-66, I-80, I-83, etc.)

Infection From Pure Culture.

Experiment II-10A; January, 1906. Soaked 50 good lemons for twenty-two hours in a bucket of water, into which had been emptied a flask culture of *Pythiacystis citrophthora;* 84% developed brown rot.

Soaked 50 more lemons in a bucket of plain water as a check: no decay resulted.

Orchard Soil in Water Produces Infection.

See experiments on soil from different depths, and all later water-disinfection experiments. I-83, I-96, IV-17, etc., etc.

Wash Water May Be Infectious.

Experiment I-12; July, 1905. Soaked 5 boxes of lemons (about 1,000) in tank of wash water over night; all but 10 lemons developed brown rot.

Experiment I-36; August, 1905. Soaked 50 good lemons in wash water and sediment, after running washer all day; 29 developed brown rot.

Soaked same number in plain water; no decay developed.

Experiment II-3; July, 1905. Soaked lemons which had just been washed as follows: 126 lemons in plain water for fifteen hours, 3% brown rot developed; 129 lemons in water from washer for fifteen hours, 80% brown rot developed; 131 lemons in sediment and wash water for sixteen hours, 100% brown rot developed.

Experiments in Infecting Washer With Soil.

Experiment IV-1 (in part); March, 1906. Dumped a bucket of infected soil into the washer tank, making the water very muddy. Then ran through 26 boxes of lemons in the usual manner; 991 lemons with original brown rot were counted out during the following six weeks. (This lot is shown in figure 25.) Also dipped out a bucketful of the water, and soaked 50 lemons in it for two hours; all developed brown rot.

See also several disinfection experiments. IV-11, IV-14, etc.

Brown Rot Infection From Washer Padding.

Experiment I-41; August, 1905. Soaked pieces of sheepskin padding and rags from the washer in a bucket of water over night; then soaked 50 good lemons all day in the same water; 9 became affected with brown rot.

Brown-Rot Tests of Soil From Different Depths and Locations.

Experiment I-83; September, 1905. Tested the top and bottom soil from boxes of freshly infected earth. Soil from surface soaked in water with good lemons gave 100% brown rot; soil from bottom of box, about eight inches deep, gave 88%; fruit in first lot completely covered with infections; not so abundant in second.

Experiment I-96; September, 1905. Soaked a small quantity of earth from following depths in infected ground in buckets of water with good lemons: from first two inches, 100% brown rot produced; from 4 to 7 inches, 92% brown rot, fewer infections; below 7 inches, 44% brown rot, fewer infections and slower development.

Experiment IV-17; May, 1906. Took samples of soil from following locations, and soaked each in bucket of water with 50 good lemons: Surface soil from under a lemon tree in an orchard where the ground under the trees had been kept well stirred; no decay resulted. From under a tree about one hundred yards from the last, in an orchard where the ground had not been so stirred; 100% brown rot. From an orchard where some rot occurred, but not worst; 76% brown rot. From another part of same orchard where rot was very bad; 100% brown rot. From an orchard near last, but on higher, well-drained soil; no decay. Check—Plain water with no soil; no decay.

Experiment IV-28; May, 1906. Soaked samples of soil as follows, in buckets of water with good lemons: Soil from under a lemon tree where there was brown rot last winter; produced 78% brown rot. From bare land, a few rods from the orchard; no decay.

From another orchard where no brown rot had been seen in the fruit; no decay.

Experiment IV-30; May, 1906. Took samples of soil from each of four sides of a lemon tree at the following depths, in an orchard badly affected with brown rot, mixed the four from each depth together, and soaked in a bucket of water with good lemons: Surface, produced 100% brown rot; 6 inches, 88%; 12 inches, 66%; 18 inches, 68%; 24 inches, 100%.

Experiment IV-31; May, 1906. Same as last, from another orchard. Surface, 70%; 6 inches, 16%; 12 inches, no decay; 24 inches, 100%.

Experiment IV-32; June, 1906. Same as last two. Surface, 100% brown rot; 6 inches, 2%; 12 inches, 90%; 24 inches, 28%.

Experiment V-6; June, 1906. Took samples of soil at different distances out from the edge of a lemon orchard, and soaked in buckets of water with good lemons. Surface soil under tree in outside row, 100% brown rot; 6 feet out from tree, no decay; 30 feet out, 2%.

Experiment V-7; June, 1906. Test in usual manner of soil from different depths in orchard badly affected with brown rot. Surface, 96% brown rot; 24 inches, no decay; 36 inches, no decay; 42 inches, no decay; 48 inches, 14%; 54 inches, 10%.

Effect of Drying Infected Soil.

Experiment I-80; September, 1905. Infected three boxes of soil very thoroughly with brown rot, so that good lemons laid on the surface would all rot. Then allowed the soil to become thoroughly dry, standing for several weeks. After this the soil was wet up again, and 40 good lemons laid on the surface in each box. In one box two brown rots developed; this was all the infection that took place.

Experiment I-87; September, 1905. A box of soil was made very infectious, and then dried for a month. Soaked up, and placed good lemons on the surface; no decay developed.

Chemical Treatment of Infected Soil.

Experiment I-30; August, 1905. Infected the soil in several boxes with brown rot; then made the following applications to the soil in each box, and put 40 good lemons on the surface: 1. Infected soil, no treatment, 23 of the good lemons developed brown rot; 2. Surface covered

with lime, no decay; 3. No treatment, 31 brown rots; 4. Surface covered with sulphur, no decay; 5. No treatment, 32 brown rots; 6. Soil soaked with 3% copper sulphate, no decay.

Experiment I-65; August, 1905. Infected soil used in experiment I-33 was divided into two plots: A was well soaked with 1-12% copper sulphate; B nothing. Good lemons then laid on the surface of each. On A, 94% developed brown rot; on B, 100%. The fungus became very abundant on the surface of both plots.

Experiment I-66; August, 1905. Prepared three boxes of infected soil, and soaked A with 1-10% copper sulphate, B with 1-100%, and C with 1-200%; then laid good lemons on the surface of each. A developed 35% brown rot, B 60%, C 65%.

Experiments I-90 and I-104; September, 1905. Soaked ground beneath a lemon tree with 280 gallons of 1-100% copper sulphate. Two weeks later tested the soil by soaking a little of it in water with good lemons; 100% brown rot resulted.

Water Disinfection With Formalin.

Experiment I-48; August, 1905. Placed 10 affected lemons in each of three buckets of water, and soaked seven hours; then removed and put 50 good lemons in each; also added to A formalin to make 1-5%, and soaked over night; with B soaked the good lemons in the infected water over night, then in 1-3% formalin for 2 hours; in C soaked the 50 good lemons in infected water without any treatment, as a check. A developed no brown rot, lemons slightly burned by the formalin, 70% *blue mould;* B, 100% brown rot; C, 100% brown rot.

Experiment I-61; August, 1905. Infected four buckets of water as in last. After adding disinfectant, soaked 50 good lemons over night in each. A, formalin 1-5%, no brown rot, 94% *blue mould;* B, formalin 1-10%, no brown rot, 52% *blue mould;* C, 1-20% formalin, no brown rot, 8% *blue mould;* D, check, no disinfection, 100% brown rot.

Experiment II-4; July, 1905. Soaked 100 lemons in each of following solutions for fourteen to sixteen hours: 1% formalin, badly burned, 61% *blue mould* developed; 1-2% formalin, burned, 41% *blue mould;* 1-10% formalin, slightly burned, 40% *blue mould.* Water not infected with brown rot in these.

Experiment II-7; December, 1905. Water infected with affected lemons. Good lemons, soaked twenty-two hours; 1-200% formalin, 2% brown rot; 1-500% formalin, 70%; 1-1,000%, 60%; check, 100%.

Experiment II-10B; January, 1906. Same as last. 1-100% formalin, no decay; 1-150% formalin, no decay; 1-200% formalin, no decay; check, 94% brown rot.

Experiment IV-14; April, 1906. Dumped a bucketful of infected orchard soil into the tank of a washer, making the water very muddy; then ran through 10 boxes of lemons; 90 original brown rots developed in these. Also soaked 50 lemons in a bucketful of the same water for three hours; all developed brown rot.

Then put into the same water in washer, formalin to make 1-500%; ran through another 10 boxes; 110 original brown rots developed in these. Soaked 50 lemons three hours in a bucketful of the same water; 28 developed brown rot.

Then put into the same water in washer more formalin to make 1-125%; ran through 10 boxes more; 78 original brown rots developed in these. Soaked 50 lemons three hours in a bucketful of the same water; 5 developed brown rot.

Experiment IV-24; May, 1906. Same method as last. Infected washer with orchard soil; then ran through 6 boxes of lemons; 49 developed brown rot. Then added formalin to make 1-125%, and washed 10 boxes more; 10 brown rots. Added more formalin to make 1-40%, and washed 10 boxes more; no brown rot developed in these.

Water Disinfection With Permanganate of Potash.

Experiment II-4; July, 1905. Soaked 100 lemons for fourteen to sixteen hours in each of the following solutions: 1-8% permanganate, stained, no decay; 1-40%, scars stained, no decay; 1-160%, scars slightly stained, no decay.

Experiment II-6; November, 1905. Infected buckets of water with affected lemons. Soaked good lemons in them for three and a half hours, with following disinfections and results: 1-50% permanganate, no decay, scars stained; 1-100%, no decay, scars stained slightly; 1-200%, no decay or staining; check, no disinfectant, 64% brown rot.

Experiment II-7; December, 1905. Same as last. Good lemons soaked twenty-two hours. 1-200% permanganate, no brown rot; 1-500%, 30% brown rot; 1-1,000%, 100% brown rot; check, 100% brown rot.

Experiment II-10B; January, 1906. Same as last. Good lemons soaked twenty-two hours. 1-200% permanganate, no decay; 1-300%, no decay; 1-400%, 56% brown rot; check, 94% brown rot.

Experiment II-12; January, 1906. Soaked lemons in plain water, with following strengths of permanganate, to test staining properties: Soaked for one-half hour, or about maximum time that fruit would remain in the washer; 1-25%, a little staining; 1-50%, no stain; 1-100%, no stain.

Experiment IV-1; March, 1906. Infected washer with a bucket of orchard soil, then ran through 26 boxes of lemons; 991 original brown rots developed in these. (Fig. 25.) Soaked 50 lemons in a bucketful of this water for two hours; all developed brown rot. Then put permanganate into the same water in the washer to make 1-125%; ran through another 25 boxes; 1 lemon developed brown rot. (Fig. 26.) Soaked 50 in a bucketful of this water for two hours; no decay.

Experiment IV-18; May, 1906. Like last. Washed 6 boxes in infected water; 122 brown rots developed. Then added permanganate to make 1-125%, and washed 10 boxes more; 8 brown rots developed. Then added more permanganate to same water to make 1-40%, and washed 10 boxes more; no brown rot developed.

Experiment IV-27; May, 1906. Added two double handfuls of infected soil to a number of buckets of water. In A, soaked 50 good lemons three hours, with no disinfectant; all developed brown rot. In B, made 1-200% permanganate, 14% brown rot. In C, 1-100% permanganate, 30% brown rot. In D, 1-50% permanganate, 2% brown rot (1 lemon). The large amount of dirt in these buckets seemed to weaken the disinfectant.

Experiment V-9; June, 1906. Infected buckets of water with soil and soaked good lemons as follows: Check, no disinfectant, 88% brown rot; permanganate, 1-100%, 1-75%, 1-50%, and 1-25%, no decay.

Water Disinfection With Copper Sulphate.

Experiment I-52; August, 1905. Infected two buckets of water with affected lemons. Soaked 50 good lemons in each over night, as follows: Copper sulphate, 1-20%, no decay, quite badly burned; check, no disinfectant, all brown rot.

Experiment I-53; August, 1905. Soaked good lemons in infected water for fourteen hours, then divided them into six lots and soaked in 1-20% copper sulphate for periods varying from one-half hour to ten hours; brown rot developed in all, averaging 60%.

Experiment I-59; August, 1905. Infected three buckets of water with affected lemons. Soaked 50 good lemons in each for five hours, with following: 1-25% copper sulphate, no decay or injury; 1-50%, same result; check, no disinfectant, 56% brown rot.

Experiment I-84; September, 1905. Infected four buckets of water, and soaked good lemons over night. 1-500% copper sulphate, 16% brown rot; 1-1,000% copper sulphate, 24% brown rot; 1-4,000% copper sulphate, 48% brown rot; check, no disinfectant, 92% brown rot. (See further data of this experiment under "Retarding of Infection.")

Experiment I-88; September, 1905. As last. 1-2,500% copper sulphate gave 36% brown rot; 1-5,000% gave 32% brown rot; 1-10,000% gave 68% brown rot; check, no disinfectant, gave 100% brown rot. (See also under "Retarding of Infection.")

Experiment I-103; September, 1905. As last. 1-50% copper sulphate gave no brown rot; 1-100% and 1-200%, same; check, 28% brown rot.

Experiment I-105; September, 1905. Same as last, but infection from soil: Copper sulphate, 1-50%, 1-100%, and 1-200% gave no brown rot; check, 100% brown rot.

Experiment II-4; July, 1905. Soaked lemons in following solutions for fourteen to sixteen hours: 1 1-4% copper sulphate, fruit badly burned, 2% blue mould; 5-8% copper sulphate, badly burned, 2% blue mould.

Experiment II-10B; January, 1906. Soaked good lemons in infected water as follows: 1-200% copper sulphate, no decay; 1-300% copper sulphate, no decay; 1-400% copper sulphate, no decay; 1-1,000% copper sulphate, 2% brown rot; check, no disinfectant, 94% brown rot.

Experiment IV-11; April, 1906. Infected washer with orchard soil; ran through 10 boxes of lemons; 380 original brown rots developed. Soaked 50 lemons in bucket of same water for three hours; all developed brown rot. Then added copper sulphate to same water in washer to make 1-500%; washed 10 boxes more; 53 brown rots developed. Soaked 50 lemons in bucket of same water for three hours; no decay. Then added more copper sulphate to same water in washer to make 1-125%; washed 10 boxes more; 5 brown rots developed. Soaked 50 lemons in bucket of same water for three hours; no decay.

Experiment IV-22; May, 1906. Same as last. Infected water and washed 6 boxes; 81 brown rots developed. Then added copper sulphate to make 1-125%, and ran through 10 boxes more; no decay. Added more copper sulphate to make 1-40%, and washed 10 boxes more; no decay.

Experiment IV-27; May, 1906. Infected buckets of water with two double handfuls of soil. Soaked lemons as follows: 1-200% copper sulphate, 2% brown rot; 1-100% and 1-50% copper sulphate, no decay. (See experiment of same number under permanganate.)

Experiment V-1; June, 1906. Test of copper sulphate in infected water: 1-100%, 1-75%, 1-50%, and 1-25% gave no decay. Check, 100% brown rot.

Experiments With Various Disinfectants in Water.

Experiment II-7; December, 1905. Infected buckets of water with affected lemons, and soaked good lemons twenty-two hours: 1-200% boric acid gave 94% brown rot; 1-500% same gave 88% brown rot; 1-1,000% same gave 90% brown rot; 1-200% salicylic acid gave 70% brown rot; 1-500% same gave 100% brown rot; 1-1,000% same gave 60% brown rot.

The water with which these experiments were started was quite cold, and did not fully dissolve the boric and salicylic acids. This is, therefore, not an accurate test of these substances.

Experiment II-10B; January, 1906. As above, with sulphide of potash: 1-100% and 1-200% gave no decay; check, without disinfectant, gave 94% brown rot.

Test of Disinfection of Washer.

Experiment II-16; May, 1906. On the afternoon of May 3d the washer in a packing house was running with about 1-150% permanganate; next day, May 4th, washed with 1-75% permanganate. Fruit from a very badly affected orchard. Soaked 50 good lemons in each of the following:

Sediment of May 3d and plain water: 44% brown rot developed.

Sediment of May 3d and wash water of May 4th: 14% brown rot.

Wash water of May 3d: 10% brown rot.

Mixture of three fourths of wash water of May 3d and one fourth of May 4th: no decay.

Wash water of May 4th: 2% brown rot.

Plain water: no decay.

Sunken lemons of May 3d (75): all developed brown rot.

Sunken lemons of May 7th (after running all day with 1-75% permanganate): 19 out of 21 developed brown rot.

Experiments Showing Retarding of Infection by Incomplete Disinfection.

Experiments I-84 and I-88; September, 1905. Soaked good lemons in infected water, with following solutions. Brown rot developed as follows, the numbers denoting the number of affected lemons which showed on the different dates in the different lots:

	Sept. 12.	Sept. 14.	Sept. 18.	Sept. 20.	Sept 25.	Total.
Copper sulphate 1-500%	None	None	2	1	1	16%
Copper sulphate 1-1,000%	None	None	2	2	2	24%
Copper sulphate 1-2,500%	None	None	8	None	1	36%
Copper sulphate 1-4,000%	5	2	3	1	1	48%
Copper sulphate 1-5,000%	None	3	4	None	1	32%
Copper sulphate 1-10,000%	Signs	8	7	2	None	68%
Check	8	14	1	None	None	92%
Check	Signs	24	None	1	..	100%

DIRECTIONS FOR BROWN-ROT CONTROL.

1. Plant a cover crop in the orchard in September or early October, so that a thick, continuous covering will be formed as early as January. Vetch and bur-clover are recommended for this purpose. Sow well under the trees, and furrow for irrigation. Where a leguminous crop can not be grown in time to assist in checking brown rot, a sowing of barley will be found useful.

2. Toward the end of the rainy season plow-in the cover crop, and begin the work of cultivation before the ground becomes hardened. The orchard should be cultivated at frequent intervals throughout the summer, especially *under the trees.* To accomplish this the trees had best be pruned up, at least until the bottom fruit just touches the ground, when the soil underneath may be satisfactorily stirred. In bad cases hand work may be necessary at first.

3. In the season of brown-rot infection (from about January until early summer) disinfect the wash water by adding one of the following substances. Proportions given are for a one-thousand-gallon tank:

Formalin—One and one half pints in the morning, one pint after noon in the same water.

Permanganate of Potash—One pound in the morning, eight ounces after noon in the same water.

Bluestone—Same as for Permanganate.

The last named is the best substance for the purpose, and may be kept in a stock solution of two pounds to the gallon. As bluestone will slightly corrode iron, tanks of this metal should be kept painted with asphalt paint.

4. Lemons infected in the orchard should be carefully eliminated during the process of picking and washing.

5. Keep a sharp lookout for any possible cases of rot in the curing tents. Affected boxes should be carefully picked over, the rotting lemons thrown out, and those lying in contact with them put by themselves for further inspection.

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1902. Report of the Agricultural Experiment Station for 1898-1901.
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